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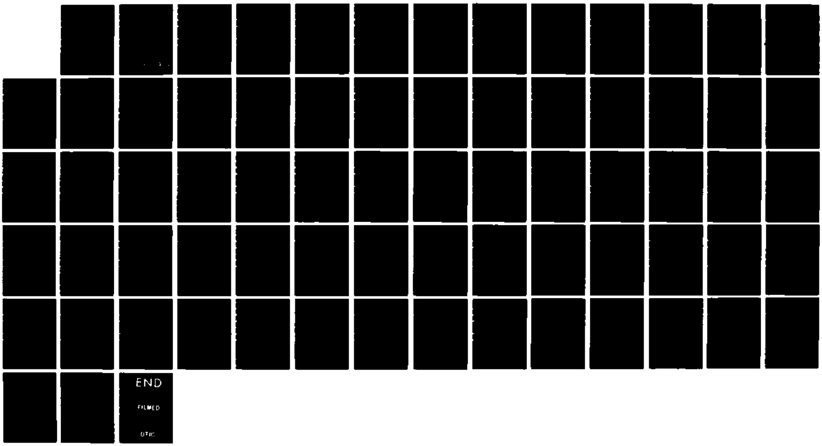

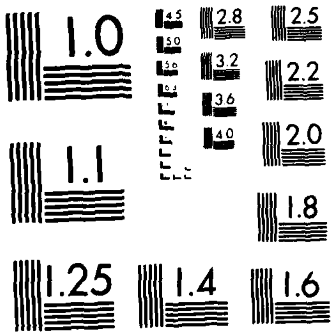

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Field Validation of Statistically Based Acceptance Plan for Bituminous Airport Pavements

Volume 2—Statistical Analysis of Marshall Properties of Plant-Produced Bituminous Materials

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NOTICE

Technical Report Documentation Page

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16. Abstract Two aspects concerning evaluation by the Marshall method of bituminous airport pavement construction were addressed. Results from field Marshall and extraction tests were analyzed to identify correlations among the Marshall properties--stability, flow, and air voids--and asphalt content and aggregate gradation. This was done to evaluate the implementation of a multiple price adjustment system based on Marshall properties, and for the development of mathematical models for estimating each property from the percent asphalt content and aggregate gradation. Data were obtained from 5 airport paving projects; however, 2 of these had such small tonnages that there were not sufficient data to prove meaningful.

A moderately low negative correlation exists between stability and air voids while no statistically significant correlation was found to exist between stability and flow. The flow and air voids correlations were not consistent among the two projects considered, with one suggesting a moderately low negative correlation, and the other no statistically significant one. The mathematical models developed for stability, flow, and air voids from extracted asphalt content and aggregate gradation were not good predictors of those properties. This is probably due primarily to the relatively high sampling and testing variability associated with the field extraction tests.

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PREFACE

This report presents the findings of a research project entitled "Field Validation of Statistically-Based Acceptance Plan for Bituminous Airport Pavements", Report No. DOT/FAA/PM-84/12, that was conducted to investigate the use of Marshall properties for acceptance purposes. The results of the research effort are presented in the series of reports listed below:

Burati, J.L., Brantley, G.D. and Morgan, F.W., "Correlation Analysis of Marshall Properties of Laboratory-Compacted Specimens," Final Report, Volume 1, Federal Aviation Administration, May, 1984.

Burati, J.L., Seward, J.D. and Busching, H.W., "Statistical Analysis of Marshall Properties of Plant-Produced Bituminous Materials," Final Report, Volume 2, Federal Aviation Administration, May, 1984.

Burati, J.L. and Seward, J.D., "Statistical Analysis of Three Methods for Determining Maximum Specific Gravity of Bituminous Concrete Mixtures," Final Report, Volume 3, Federal Aviation Administration, May, 1984.

Nnaji, S., Burati, J.L. and Tarakji, M.G., "Computer Simulation of Multiple Acceptance Criteria," Final Report, Volume 4, Federal Aviation Administration, August, 1984.

Burati, J.L., Busching, H.W. and Nnaji, S., "Field Validation of Statistically-Based Acceptance Plan for Bituminous Airport Pavements — Summary of Validation Studies," Final Report, Volume 5, Federal Aviation Administration, September, 1984.

The application of multiple price adjustments is significantly more involved than the case when only one property, e.g., density, is considered. Since the Marshall properties (i.e., stability, flow and air voids) are physically related, they can be expected to be statistically correlated. If this is truly the case, then it may not be sufficient to treat each of the three properties individually. It is necessary to determine whether correlations exist among these properties, and whether such correlations should be considered when developing acceptance plans.

The objectives of the research described in the reports listed above include:

1. Review current methods for determining maximum specific gravity for use in air voids calculations for possible incorporation into the FAA Eastern Region P-401 specification,

2. Investigate the use of price adjustments when more than one characteristic is being used for acceptance purposes and recommend to the FAA potential procedures for dealing with multiple price adjustments,

3. Develop the procedures necessary to evaluate the performance of multiple properties acceptance plans,

4. Implement proposed Marshall properties acceptance plans on demonstration projects under field conditions, and

5. Attempt to correlate values of asphalt content and aggregate gradation with those from Marshall tests to determine whether or not correlations exist among these properties.

This report, Volume 2, presents the findings of an analysis of field data from asphalt pavement construction projects to determine whether correlations exist among the Marshall properties. The results of a laboratory analysis are presented in Volume 1. How correlations can be considered in the development of price adjustment systems is presented in subsequent volumes.

CHAPTER I

INTRODUCTION

The Federal Aviation Administration (FAA) Eastern Region along with other state and federal engineering agencies has adopted the Marshall method for analyzing the properties of asphalt pavements. These procedures, standardized by the American Society for Testing and Materials (ASTM), establish criteria used to evaluate laboratory designed asphalt concrete and to control plant production and field placement. The 2 principal features of the Marshall method are a density and air voids analysis and a load-deformation test for compacted asphalt paving mixtures.

Using ASTM procedure D-2726, "Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens" (1), the density is determined by multiplying the bulk specific gravity by 62.4 lb/ft^3. The air voids represent the percentage of the total volume that is occupied by air spaces within the compacted specimen. This is determined mathematically using the bulk specific gravity and the maximum specific gravity of the paving mixture.

Stability and flow values, related to the load and deformation of the material, are determined simultaneously by testing a standard specimen under a compressive load at a constant rate of deformation of 2 inches per minute. The stability value is the maximum load resisted in pounds and the flow value is the deformation of the specimen, in units of 1/100-inch, measured at the maximum load.

In 1978, the FAA Eastern Region incorporated a statistically-based acceptance plan into its bituminous surface course specification (Item P-401). That specification provided a price adjustment system based on the average mat density for material placed during a day's production. Stability, flow, and air voids were evaluated only for substantial compliance with specification tolerance limits.

In 1980, an FAA-sponsored research project was conducted to evaluate the original price adjustment system and to expand the statistical specification to include acceptance characteristics and price adjustments for the Marshall properties. The final report from that effort (2) recommended that the standard deviation, rather than the range, be used to determine acceptance levels for mat density. However, data were insufficient concerning interrelationships among the 3 properties and development of price adjustment factors for the Marshall properties was incomplete.

When 2 or more properties are highly correlated, it is possible that they may be measuring the same characteristics of the mixture. If this is the case, then a price adjustment should be applied to only one or the other of the properties to avoid penalizing the contractor twice

for deficiencies in a single characteristic. Since the Marshall properties are determined from a single test this would indicate that the properties may be physically related. Before multiple price adjustments can be applied for the Marshall properties it is necessary to identify any relationships that might exist.

Basis for Study

The current research project was a direct result of the initial research recommendations concerning the development of a statistically-based multiple price adjustment plan for bituminous paving projects. Three major areas of investigation were suggested by the 1980 report (2). These are:

1. a laboratory analysis to determine whether correlations exist among the Marshall properties under controlled conditions;

2. a computer simulation analysis to investigate various acceptance plans using data available from state and federal agencies that have used statistically-based acceptance plans; and,

3. an analysis of data collected on bituminous concrete runway pavement construction projects to determine if a multiple price adjustment plan is applicable.

This report presents the results of an analysis of field data collected from paving projects completed during the 1981 construction season.

Research Objectives

The purpose of this study was to investigate the following objectives based on construction data collected from acceptance and quality control test results.

1. Determine if significant correlations exist among pairs of the Marshall properties--stability, flow, and air voids. In particular, stability versus flow, stability versus air voids, and flow versus air voids are considered.

2. Develop mathematical models to predict Marshall stability, flow, and air voids from extracted asphalt content and aggregate gradation, if correlations are found to exist.

Research Benefits

The analysis of acceptance and quality control test results from bituminous paving projects, along with an analysis of material tested under controlled conditions in the laboratory, will be used to determine if statistical correlations exist among Marshall stability, flow, and air voids. If correlations are found to exist among the Marshall properties, then multiple price adjustment factors that consider these correlations can be established and new price adjustments can be added

to the current FAA price adjustment system for density.

The results of this research were also used to determine whether correlations exist between extracted asphalt content and aggregate gradation and the corresponding Marshall test results. Where significant correlations exist, a mathematical model was developed to give a contractor the ability to adjust the asphalt content and/or aggregate gradation at the mixing plant to achieve a desired Marshall stability, flow, or air voids.

Table V. Rochester Project, Job Mix Formula, Quality Control Limits, and Construction Results

Rochester							
		Quality Control Limits				Results	
		Lower		Upper			
Property	JMF	Action	Warning	Warning	Action	Mean	Std. Dev.
Marshall Test							
Stab	2561	1800	2150	-	-	3207.3	223.0
Flow	12.5	9	10	14	15	12.50	1.24
Voids	3.5%	1.7%	2.0%	5.0%	5.3%	3.69%	0.45%
Extraction Test, %							
A.C.	6.2%	5.6%	5.8%	6.6%	6.8%	6.05%	0.27%
S3/4"	100.0	*	*	*	*	100.0	0.0
S1/2"	98.6	90 6%	91.6%	100.%	100.%	98.07	1.00
S1/4"	71.6	*	*	*	*	71.05	3.81
S1/8"	61.4	53.4%	54.4%	68.4%	69.4%	57.40	4.11
S#20	35.7	*	*	*	*	32.95	1.94
S#40	26.4	21.4%	22.4%	30.4%	31.4%	24.71	1.64
S#80	9.8	*	*	*	*	9.63	1.31
S#200	3.8	0.8%	1.8%	5.8%	6.8%	3.32	0.91

Stab - Stability value
Voids - Air Voids value
A.C. - Asphalt Content
S3/4 - Percent passing 3/4" sieve
S#20 - Percent passing #20 sieve
* - No quality control limits required

Table IV. BWI Project, Job Mix Formula, Quality Control Limits, and Construction Results

BWI							
		Quality Control Limits				Results	
		Lower		Upper			
Property	JMF	Action	Warning	Warning	Action	Mean	Std. Dev.
Marshall Test							
Stab	2330	1800	2150	-	-	2794.0	68.92
Flow	11.5	8	10	14	16	10.60	0.54
Voids	3.6%	1.7%	2.0%	5.0%	5.3%	3.40%	0.20%
Extraction Test, %							
A.C.	5.5%	4.9%	5.1%	5.9%	6.1%	5.64%	0.07%
S3/4"	100.0	*	*	*	*	100.0	0.0
S1/2"	93.6	85.6%	86.6%	100.%	100.%	93.30	1.25
S3/8"	81.7	*	*	*	*	83.30	2.31
S#4	63.2	55.2%	56.2%	70.2%	71.2%	63.86	3.02
S#8	51.0	*	*	*	*	51.40	1.89
S#16	41.7	*	*	*	*	42.48	1.69
S#30	32.5	*	*	*	*	33.17	1.50
S#50	19.1	14.1%	15.1%	23.1%	24.1%	18.82	0.88
S#100	9.0	*	*	*	*	10.25	0.53
S#200	4.9	1.9%	2.9%	6.9%	7.9%	5.96	0.34

Stab - Stability value
Voids - Air Voids value
A.C. - Asphalt Content
S3/4" - Percent passing 3/4" sieve
S#4 - Percent passing #4 sieve
* - No quality control limits required

Flow measurements were made by reading values visually from a deformation gauge while the test was being conducted. Although no actual testing was observed, discussions wih operators and technicians were impressive. All parties showed considerable experience in bituminous material production and paving. Table IV lists the JMF, the quality control tolerances, and the resulting means and standard deviations for the project Marshall and extraction tests results. Marshall and extraction test data for the BWI project are listed in Appendix A.

The standard deviation results for stability and asphalt content in Table IV are not consistent with other historical data or the results from the other 2 projects. They are considerably smaller than the values generally obtained. However, the fact that the magnitudes of the standard deviations are low does not necessarily indicate that the correlations among the results are not appropriate. For this reason, all analyses conducted on the other projects were conducted on the BWI data as well.

Rochester Project

The Rochester project was the smallest of the 3 projects studied with only 16 working days and 53 sublots tested. During the visit by the researchers, sampling and testing procedures were observed during the production and paving of the test strip. All procedures were carried out in strict compliance with the ERLPM. Table V lists the JMF, the quality control tolerences, and the resulting means and standard deviations for the Rochester project Marshall and extraction tests results. The Marshall and extraction test data for the Rochester project are listed in Appendix A.

Trend Analysis Results

Analyses of the data to determine if trends developed from each project were performed using an analysis of variance and visual observations of the data plotted against workday. References are made to the plots of each Marshall property versus workday in the discussions concerning the analysis of variance results.

Analysis of Variance

The one-way ANOVA procedure was conducted to test whether the stability, flow, and air voids results for each project varied from day to day. Variations can be linearly increasing or decreasing, or a combination of increasing and decreasing relations segmented throughout the project duration. The analysis procedure generated F-statistics for testing the null hypothesis that there is no difference in the various Marshall results with changes in workday.

The results of the analysis, which include the F-statistic and probability associated with getting a higher F value, are given in Table VI for each of the Marshall properties from NAFEC, BWI, and Rochester.

Table III. NAFEC Project, Job Mix Formula, Quality Control Limits, and Construction Results

NAFEC							
		Quality Control Limits				Results	
		Lower		Upper			
Property	JMF	Action	Warning	Warning	Action	Mean	Std. Dev.
Marshall Test							
Stab	2220	1650	1800	-	-	2487.1	283.6
Flow	10.0	6	8	16	18	10.02	0.80
Voids	3.5%	1.4%	2.0%	5.0%	5.6%	3.34%	0.74%
Extraction Test, %							
A.C.	4.9%	4.3%	4.45%	5.35%	5.5%	4.83%	0.24%
S1"	100.0	*	*	*	*	100.0	0.0
S3/4"	99.5	*	*	*	*	99.72	0.57
S1/2"	91.7	81.7%	84.7%	96.7%	99.7%	92.47	4.54
S3/8"	84.8	*	*	*	*	85.66	3.34
S#4	57.3	*	*	*	*	60.23	3.50
S#8	41.6	32.4%	35.4%	47.4%	50.4%	43.33	3.24
S#50	14.7	7.6%	9.6%	19.6%	21.6%	15.34	1.36
S#200	5.3	2.4%	3.4%	7.4%	8.4%	5.25	0.60

Stab - Stability value
Voids - Air Voids value
A.C. - Asphalt Content
S1" - Percent passing 1" sieve
S3/4" - Percent passing 3/4" sieve
S#4 - Percent passing #4 sieve
* - No quality control limits required

CHAPTER IV

DATA ANALYSIS RESULTS

This chapter contains the results of the data analysis efforts on the field Marshall test results. As discussed previously, only 3 of the 5 projects on which data were gathered had sufficient data to be considered in the analysis. A general analysis of the results of each project studied is presented first, followed by the results of the anlaysis to determine whether any trends exist. The correlation results and the regression anlysis results are then presented. Although strict tolerences were required by the FAA with regard to testing variability, a number of variables unavoidably entered into the results. Some of these include: placement and testing under differing weather conditions, variations within the material during the course of production, variations in the mix proportions during production, sampling and testing variability.

Project Analysis Results

NAFEC Project

The NAFEC project was the largest of the 3 projects studied with 199 sublots of material tested over 51 working days. The pre-construction visit to this site was very beneficial. Observations revealed a number of problems relating to sampling and testing procedures. The random sampling procedures were not as prescribed in the ERLPM and testing procedures were lax and inconsistent. Although the technicians were certified in the use of the ERLPM procedures, serious procedural problems existed. Observations were made by FAA Eastern Region officials and the procedures were corrected. However, for the duration of the project strict compliance with ERLPM procedures can only be assumed.

Table III lists the Job Mix Formula (JMF), the quality control tolerence limits, and the resulting means and standard deviations for the NAFEC project Marshall and extraction tests results. The Marshall test data and extraction test data for the NAFEC project are listed in Appendix A.

BWI Project

The BWI project was the second largest of the 3 projects studied. A total of 67 Marshall test averages and extraction tests were conducted over 19 days of construction. A pre-construction visit to Baltimore enabled the project investigators to observe the laboratory. This laboratory lacked the quality equipment found on the other projects. On the BWI project compaction of Marshall specimens was accomplished with a hand-held compactor, whereas mechanical compactors were used on the other projects. More importantly, the testing machine for the Marshall specimens was not equipped with an automatic recording device for flow.

Regression Analysis

The other area of interest in the research effort was the development of mathematical models with the Marshall properties as dependent variables and the extracted asphalt content and aggregate gradation as independent variables. Forward Stepwise Regression (STEPWISE) and General Linear Model (GLM) procedures available within SAS (4) were used to perform the multiple regression analysis for the 3 properties.

For each sublot of material the Marshall results were grouped with the corresponding extraction test results consisting of asphalt content and the percentage of material passing the various sieve sizes. Using each of the Marshall properties individually as the dependent variable, 3 multiple regression analyses were conducted, 1 for each property. The GLM and STEPWISE procedures considered asphalt content, the sieve sizes, and interaction terms between asphalt content and sieve sizes, in the model as independent variables. The STEPWISE regression included only those independent variables that entered the model at the 50% level of significance, while the GLM regression included all of the independent variables.

CHAPTER III

DATA ANALYSIS PROCEDURES

Computer data sets were compiled for each project in preparation for the analysis. The Statistical Analysis System (SAS) (4), a system of statistical programs, was used for all aspects of the data analysis.

Project Analysis

This section presents the overall results of the NAFEC, BWI, and Rochester projects individually. A comparison is made between the job mix formula accepted by the FAA Eastern Region prior to construction and the resulting contractor performance.

Time Trend Analysis

For each project, an analysis was made to determine whether time had an effect on the 3 Marshall results. The data were anlyazed, first, by using an Analysis of Variance (ANOVA) (4) for each of the Marshall properties with workday as a treatment effect. The ANOVA procedure was used to determine if workday had an effect on the average daily Marshall results. The second analysis was to observe scatter plots of the individual Marshall properties plotted against working day. Each day contained data for the individual sublots of material produced and tested. The visual analysis of the plots was used to determine if an increasing or decreasing variation trend existed as the projects progressed.

Correlation Analysis

The main emphasis of this investigation was to determine whether correlations exist among the 3 Marshall properties for material placed under field conditions. The correlations considered are Marshall stability with Marshall flow, Marshall stability with air voids, and Marshall flow with air voids.

A correlation analysis measures the amount of association between 2 variables. The correlation coefficient is a measure of this association, and for the purposes of this research was based on a linear relationship. The sample correlation coefficients can range from -1.0 to +1.0. Negative correlation coefficients imply that as one variable increases the other decreases, whereas positive correlations imply that as one variable increases the other also increases. The magnitude of the correlation coefficient represents the significance of the relationship between the 2 variables. Coefficients near 0 result from scattered data, and indicate that as one variable increases there is no consistent effect on the other variable.

Data Analysis Procedure

Analyses were conducted on each project separately since differences in testing procedures, material, time, location, etc., could not reasonably be handled by any analysis procedure. Comparisons among projects were made after the same analysis procedure was used on each of the 3 projects.

Statistical analyses were performed on the data to determine whether any trends were present and which projects, if any, should be eliminated from consideration due to insufficient sample size. Each project was then analyzed to determine whether correlations existed within the Marshall properties or among the Marshall properties and asphalt content and aggregate gradation.

PRODUCER: ____________________ SPEC: ____________

PROJECT: ADAP No. ____________ DATE: ____________

TEST PERFORMED BY: ____________ AFFILIATION: ____________

EXTRACTION TEST

1. WGT. OF SAMPLE: W_1 = ________ gms

2. WGT. OF WATER IN SAMPLE: W_2 = ________ gms

3. WGT. OF EXTRACTED AGGREGATE: W_3 = ________ gms

   NOTE: ADD THE INCREASE IN WGT OF FILTER RING TO W_3.

4. WGT. OF ASH IN EXTRACT: W_4 = ________ gms

5. BITUMEN CONTENT OF DRY SAMPLE, %:

$$\% AC = \frac{(W_1 - W_2) - (W_3 + W_4)}{W_1 - W_2} \times 100$$

% AC = ____________ x 100 = ____________ %

6. GRADATION:

SIEVE												
RET. WGT.												
% RET.												
% PASS.												
SPEC.												

Figure 2. Sample Extraction Test Form

DATE: ____________ CALCULATIONS BY: ____________

AFFILIATION : ____________

SUMMARY SHEET - MARSHALL TESTS

	STABILITY	FLOW	AIR VOIDS
SUBLOT 1 SPECIMEN NO. 1-1			
SPECIMEN NO. 1-2			
SPECIMEN NO. 1-3			
SAMPLE INCREMENT (AVERAGE)			
SUBLOT 2 SPECIMEN NO. 2-1			
SPECIMEN NO. 2-2			
SPECIMEN NO. 2-3			
SAMPLE INCREMENT (AVERAGE)			
SUBLOT 3 SPECIMEN NO. 3-1			
SPECIMEN NO. 3-2			
SPECIMEN NO. 3-3			
SAMPLE INCREMENT (AVERAGE)			
SUBLOT 4 SPECIMEN NO. 4-1			
SPECIMEN NO. 4-2			
SPECIMEN NO. 4-3			
SAMPLE INCREMENT (AVERAGE)			

Figure 1. Sample Marshall Test Summary Form

Table II. Selected Projects for Field Data Analysis

Project Description	
National Aviation Facilities Experimental Center	
DESIGNATION	NAFEC
CONTRACTOR:	A.E. Stone, Inc. Pleasantville, New Jersey
BITUMEN PLANT:	H&B (Drum Mixer) capacity; 250 tons/hr. McCarter (Batch) capacity; 5000 lbs.
PROJECT DESCRIPTION:	Main Runway 13-31 and Taxiway B Reconstruction overlay.
Baltimore Washington International Airport	
DESIGNATION:	BWI
CONTRACTOR:	Bituminous Construction Co., Inc. Baltimore, Maryland
BITUMEN PLANT:	(Drum Mixer) capacity; 600 tons/hour
PROJECT DESCRIPTION:	Overlay of Runway 15-33.
Rochester-Monroe County Airport	
DESIGNATION:	Rochester
CONTRACTOR:	Frank diMino, Inc. Rochester, New York
BITUMEN PLANT:	Barber-Green (Drum Mixer)
PROJECT DESCRIPTION:	Rehabilitation, Runway 10-28.

Table I. Suggested Projects for Field Data Analysis

Project	Location	Tonnage
National Aviation Facilities Experimental Center	Pomona, New Jersey	98,000
Baltimore-Washington International Airport	Baltimore, Maryland	32,000
Rochester-Monroe County Airport Rehabilitation Runway 10-28	Rochester, New York	20,000
Rochester-Monroe County Airport Reconstruction Taxiway "D"	Rochester, New York	3,300
Manassas Municipal Airport	Manassas, Virginia	5,850

Data Collection

Five projects were selected by the FAA Eastern Region for the collection of field data. The project locations and respective tonnages are shown in Table I. Two of the projects, Rochester Taxiway and Manassas, had low tonnages and were not used in the analysis. Table II provides more detailed information on the 3 projects evaluated. Data collected on the projects were received directly from the FAA Eastern Region office. Data for each project consisted of acceptance tests, including the various Marshall stability, flow, and air voids results, and quality control tests that contained results for extracted percent asphalt content and aggregate gradation.

The plant-produced mixture is tested on a lot basis. A lot consists of:

1. one day's production not to exceed 2,000 tons, or

2. a half day's production where it is expected to consist of between 2,000 and 4,000 tons, or

3. similar subdivisions for tonnages over 4,000 tons.

Each lot consisted of 4 equal subdivisions called sublots. Three Marshall tests and 1 extraction test were performed on each sublot of material by randomly selecting the truck from which the material was to be taken. Each set of Marshall tests consisted of the average of 3 test specimens prepared from the same sample.

Results were received on a continuous basis from each of the 5 projects and data were recorded on standard forms made available by the FAA Eastern Region for Marshall and extraction test results. A sample Marshall test summary sheet and extraction test data sheet are shown in Figures 1 and 2, respectively. Extraction test results were matched with the corresponding Marshall test results and the information was then recorded and grouped by project.

For each project, data included test results for each sublot of material; average Marshall results for stability, flow, and air voids; and an extraction test giving the percent asphalt content and percent passing the various sieves comprising the gradation.

CHAPTER II

RESEARCH PROCEDURE

The portion of the research project dealing with the Marshall properties was divided into 2 main areas. Since the research involved the analysis of data collected under field conditions, the first task was to limit variability as much as possible. The other task involved analyzing the data to determine their statistical significance in the application of multiple price adjustments for the Marshall properties of stability, flow, and air voids. All data for the research were made available by the FAA Eastern Region. Data were gatered on a total of 5 projects during the 1981 construction season.

Limiting Variability

Data were obtained from regular daily production and acceptance tests. Since there were no replicate samples taken and tested, there was no way of determining the relative amounts of sampling, testing, and production variability. If the component variability could be identified, the correlation analysis could be designed to account for these variations and precision would be improved. Unfortunately, this was not possible without interfering with the ongoing construction process. Thus, the analysis was conducted on data containing an inherent amount of variability and the need existed to limit this variability as much as possible in deriving statistical correlations.

The random sampling and testing procedure used by technicians on FAA Eastern Region construction is outlined in the Eastern Region Laboratory Prodedures Manual (ERLPM) (3). This manual includes lists of equipment required for preparation and testing of specimens and tolerance limits for testing temperature and times that are adopted from standard procedures. The manual also contains an objective random sampling procedure designed for sampling plant-produced and field-compacted material.

Pre-construction meetings were held at each project site so that all parties involved were made aware of the research effort and the information needed to conduct the field analysis. Emphasis was placed on strict compliance with the procedures outlined in the ERLPM. To further limit sampling variability, suggestions were made to conduct the extraction tests, used to determine asphalt content and aggregate gradation, from the same sample of material used in the Marshall tests. After construction began, another visit by the researchers and FAA personnel was made to each of the construction sites to certify that sampling and testing procedures were conducted in accordance with the ERLPM.

Table VI. Analysis of Variance for NAFEC, BWI, and Rochester Projects

Analysis of Variance		
Data Source	F Statistic	PR>F [a]
NAFEC		
Stability vs. Work Day	2.33	0.0001
Flow vs. Work Day	2.95	0.0001
Air Voids vs. Work Day	3.27	0.0001
BWI		
Stability vs. Work Day	1.76	0.0611
Flow vs. Work Day	1.27	0.2391
Air Voids vs. Work Day	5.31	0.0001
Rochester		
Stability vs. Work Day	2.13	0.0309
Flow vs. Work Day	1.30	0.2517
Air Voids vs. Work Day	4.15	0.0002

[a] Probability of values exceeding the F test statistic.

From an observation of Table VI the probability of test values exceeding the F test statistic, is 0.0001 for the stability, flow, and air voids comparisons with workday. This indicates that there is enough evidence to reject the null hypothesis that working day has no effect on the Marshall results. From the plots of stability versus workday, flow versus workday, and air voids versus workday, for the NAFEC data, shown in Figures 3, 4, and 5, respectively, test results show wide variations from day to day as expected from the analysis results.

On the BWI project, the probabilities of test values exceeding the F-statistic for stability and flow versus workday comparisons are 0.0611 and 0.2391, respectively. This is greater than 0.05, which indicates that there is no significant difference at the alpha = 0.05 level between either stability or flow as workday changes. An examination of Figure 7 of flow versus workday reveals that the majority of the flow test values were recorded as either 10.0 or 11.0. Air voids versus workday, on the other hand, exhibited results similar to the NAFEC project. The probability of test values exceeding the F-statistic for air voids versus workday was 0.0001 which indicates that there is a significant difference among air voids values with changes in workday.

At Rochester, the analysis showed no significant difference among flow results with variations in workday at the 5% level, with a probability of test values exceeding the F-statistic equal to 0.2517. Stability and air voids comparisons with workday indicated that at the 5% level of significance the null hypothesis that there is no difference in test values with changes in workday must be rejected. The resulting probability of test values exceeding the F-statistic for the stability and workday comparison is 0.0309, and the air voids and workday comparison is 0.0002. Since both are less than 0.05, a significant difference in stability and air voids values with changes in workday exists at the 5% level of significance.

Analysis of Scatter Plots

The plots of stability, flow, and air voids versus workday are given in Figures 3-5 for NAFEC, in Figures 6-8 for the BWI project, and Figures 9-11 for Rochester.

NAFEC Comparisons

From the stability results in Figure 3, no test results were less than the minimum specification requirement of 1800 pounds. General observation of the data shows no apparent trends throughout the course of production. Three flow values were below the minimum tolerence of 8.0, 1 on the first day and 2 on the third day of production. The remainder of the flow test results, with the exception of those between days 7 and 13, were relatively consistent. Days 7 through 13, and the slight increasing trend in the data, may be responsible for the ANOVA results indicating a significant variation with workday. Seven air voids values were found to be outside the specification limits of 2.0%

and 5.0%. Generally, the data are widely scattered throughout the specification range and no trends are apparent.

BWI Comparisons

On the BWI project, all stability results (Figure 6) were at least 500 pounds above the minimum specification requirements. The data were scattered randomly between 2650 and 2925 pounds during the project duration. No trends were apparent. Although no test results were outside the specification limits, 13 of the 19 workdays had results for flow of 10.0 or 11.0 (Figure 7). This is probably due to the fact that Marshall tests at BWI were performed using a flow gauge instead of an automatic recording instrument. This lack of variability in the flow results may have an effect on the correlation analysis and regression analysis for BWI. Air voids results in Figure 8 were within the specification limits of 2.0% and 5.0% for the entire project. The results are low the first 2 days, and then reasonably consistent.

Rochester Comparisons

The Rochester project produced the highest average stability for the 3 projects with all tests exceeding the minimum specification limit. No trends are apparent in Figure 9. No test results exceeded the maximum specification limit for flow during the course of the project, but several did approach the upper limit (Figure 10). All other test values were evenly scattered throughout the specification range with no trends occurring. All air voids results were widely scattered within specification limits throughout the project (Figure 11).

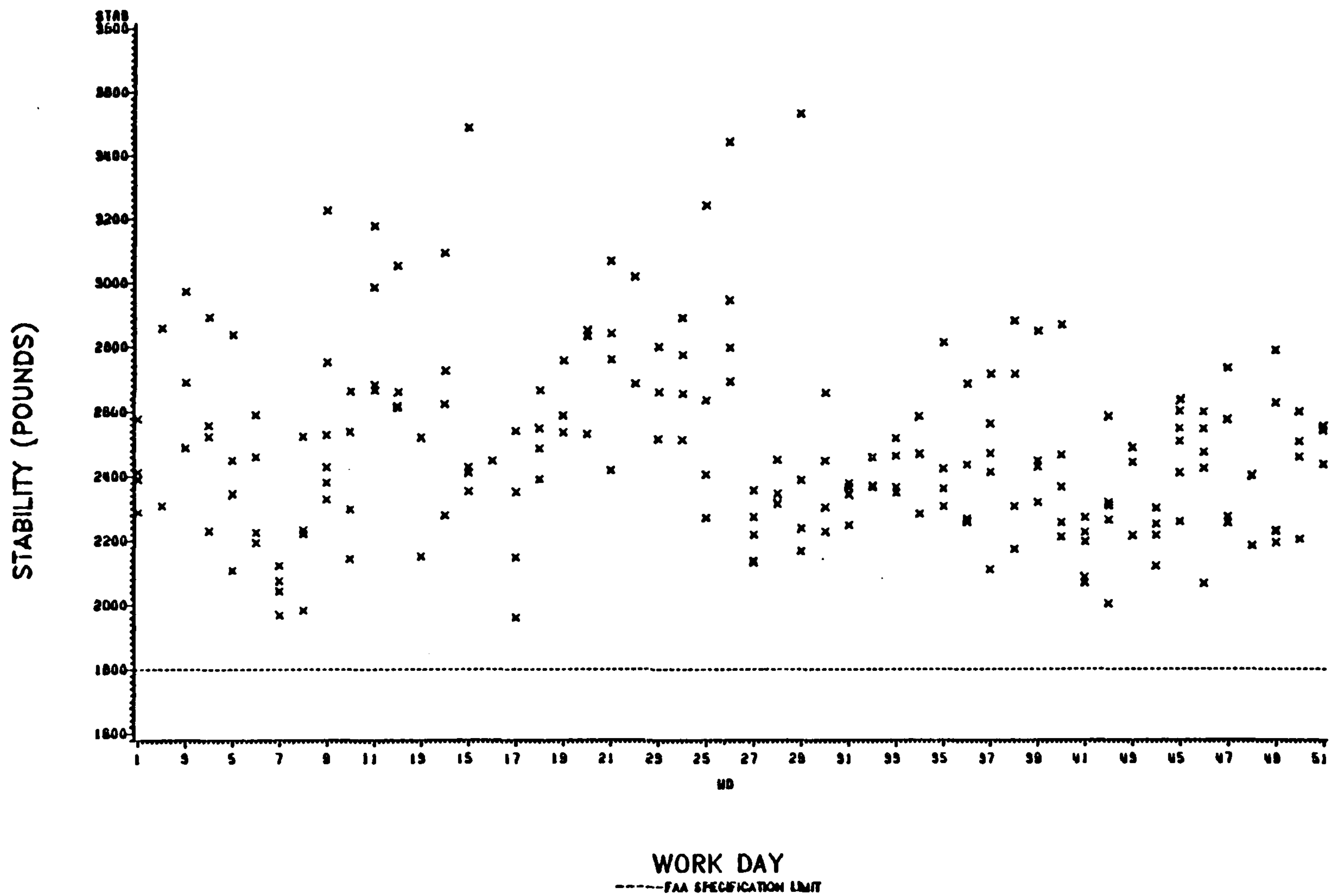

Figure 3. NAFEC Stability versus Work Day

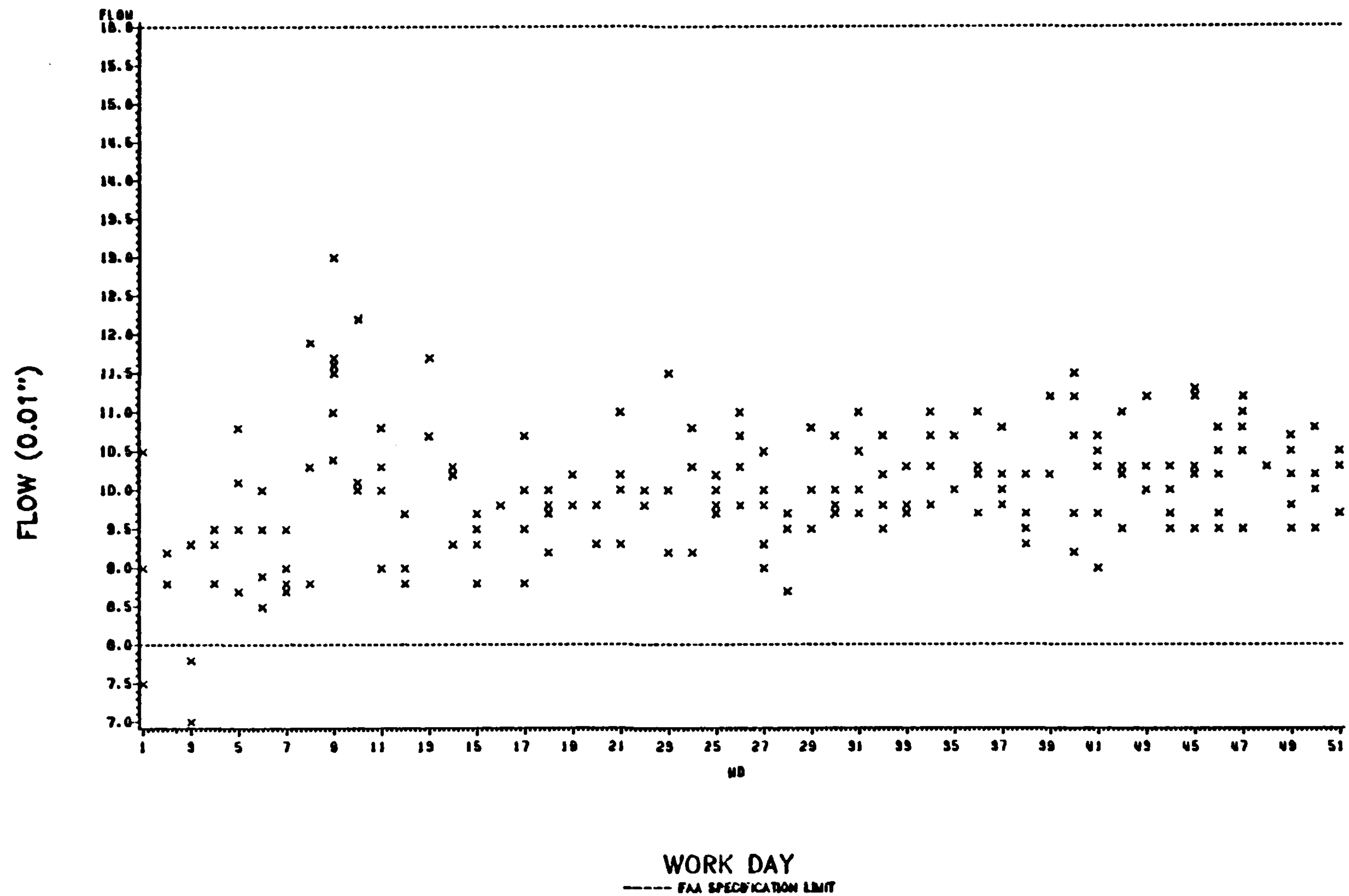

Figure 4. NAFEC Flow versus Work Day

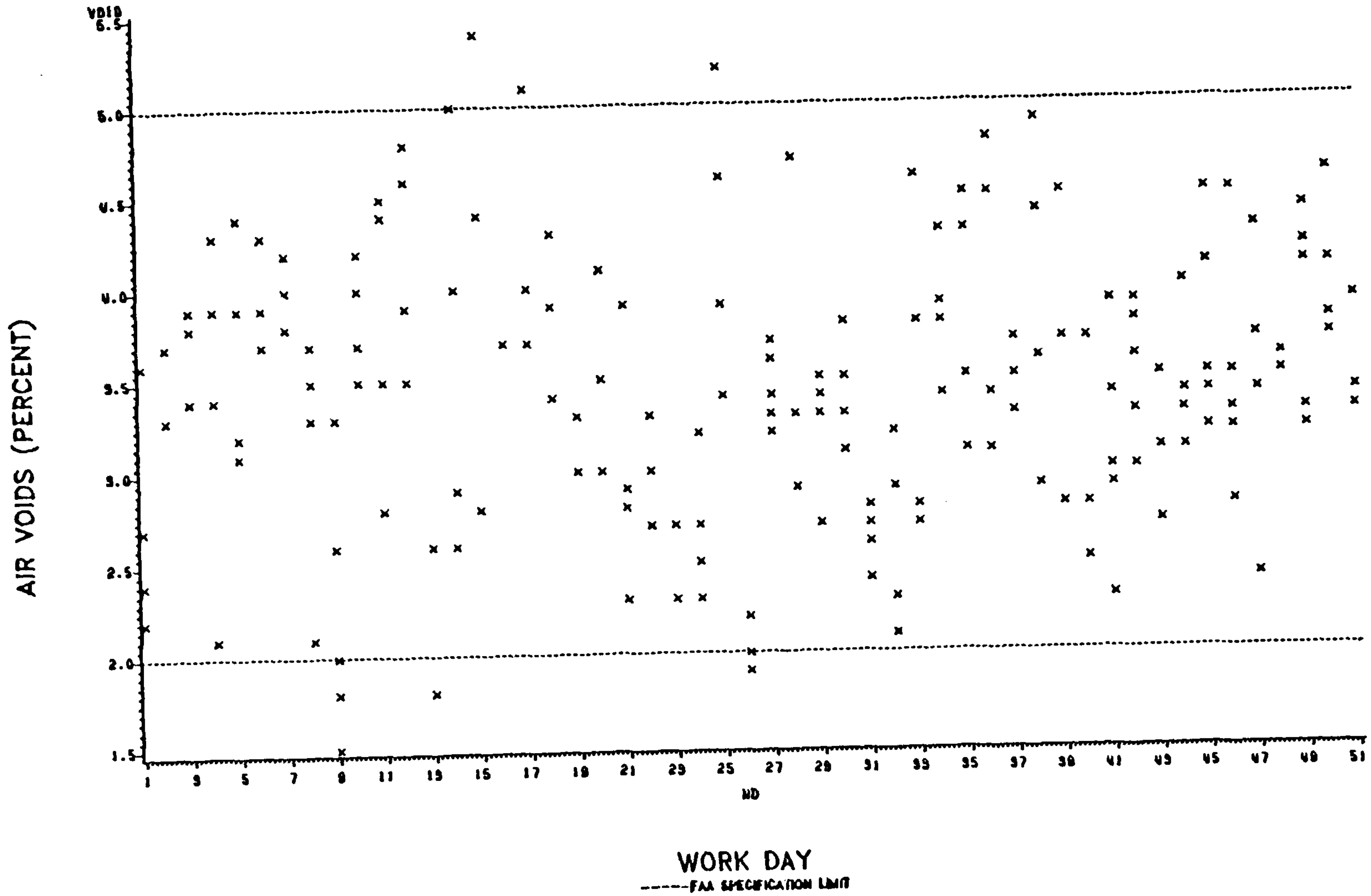

Figure 5. NAFEC Air Voids versus Work Day

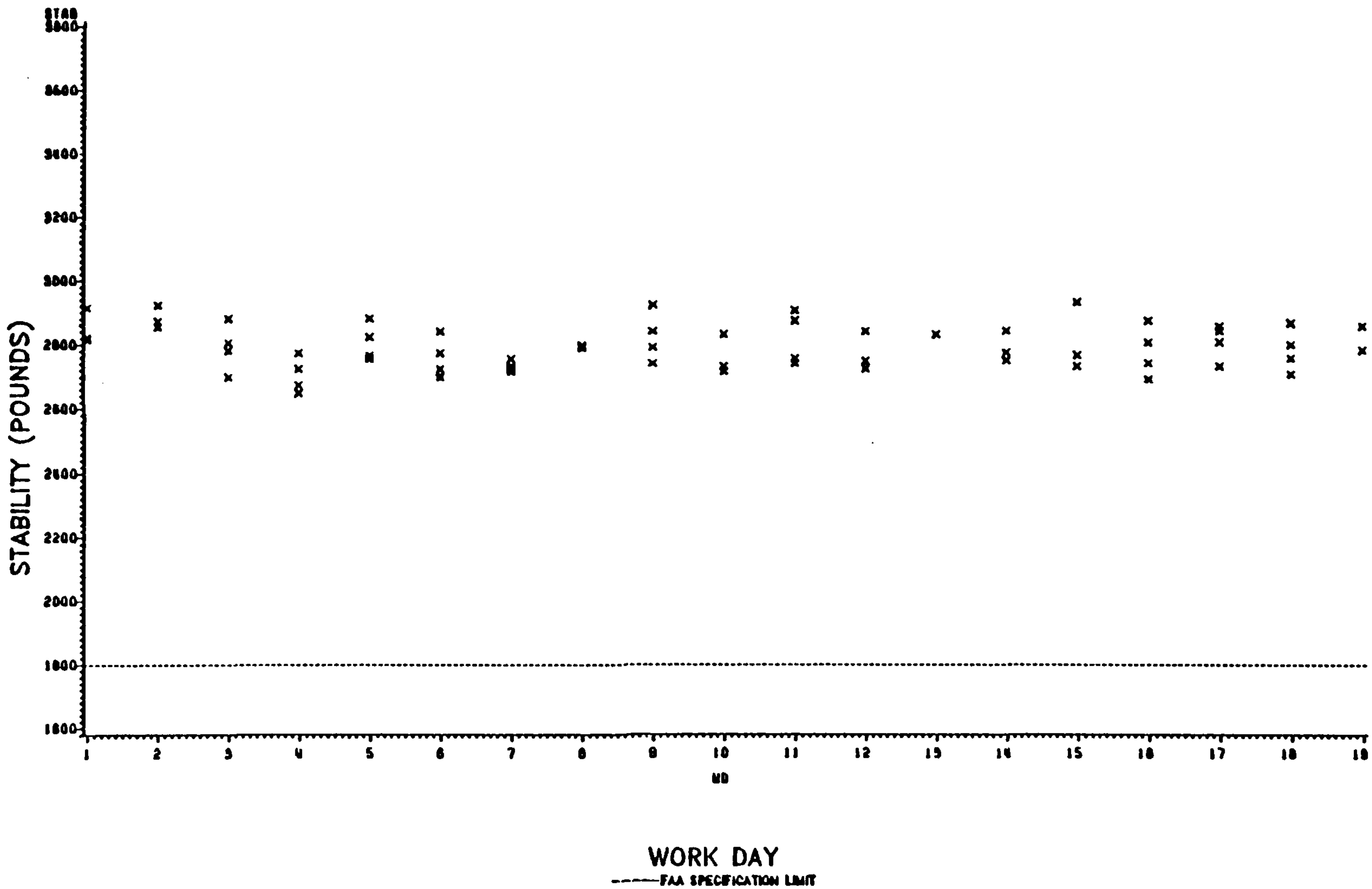

Figure 6. BWI Stability versus Work Day

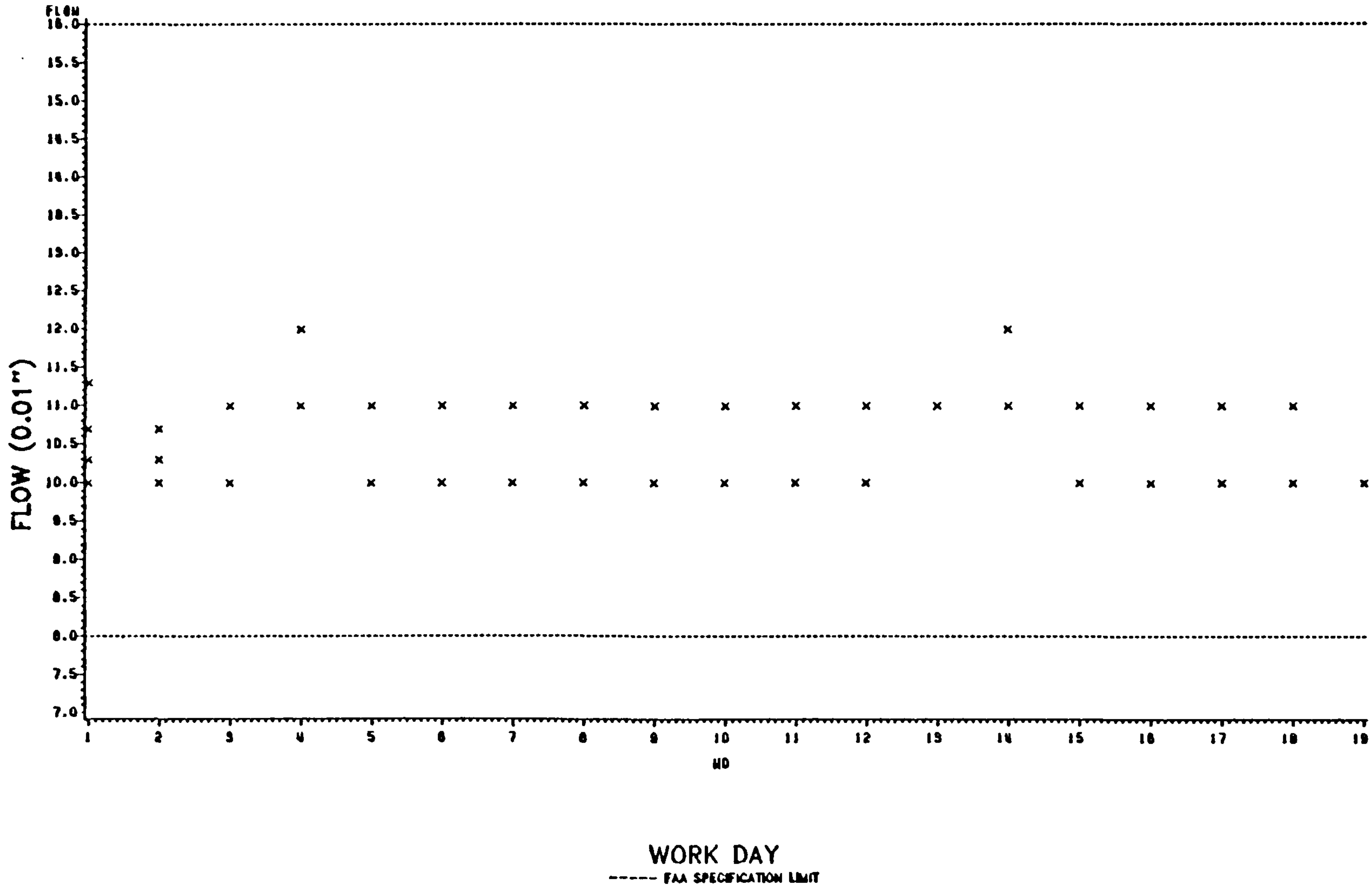

Figure 7. BWI Flow versus Work Day

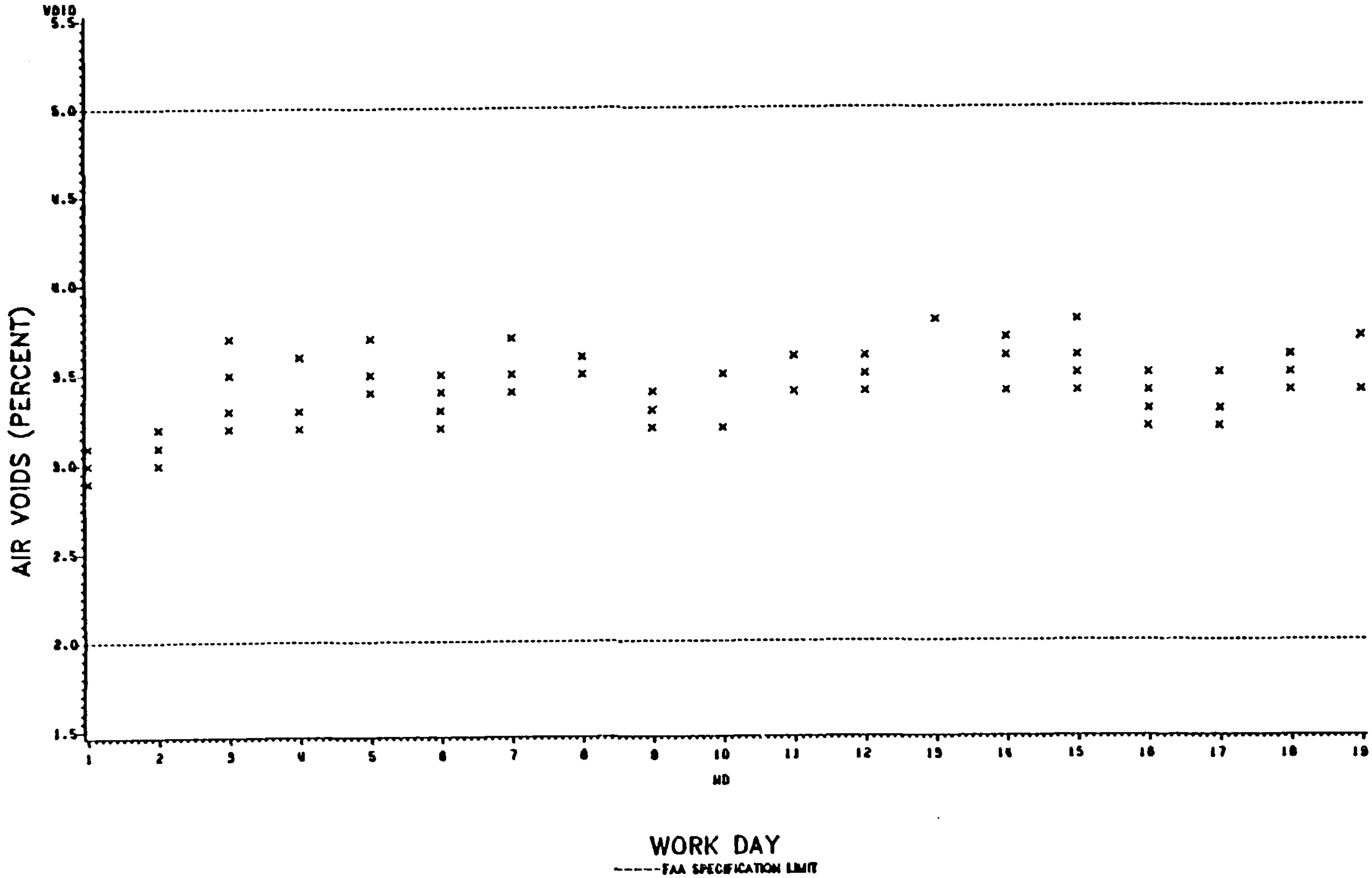

Figure 8. BWI Air Voids versus Work Day

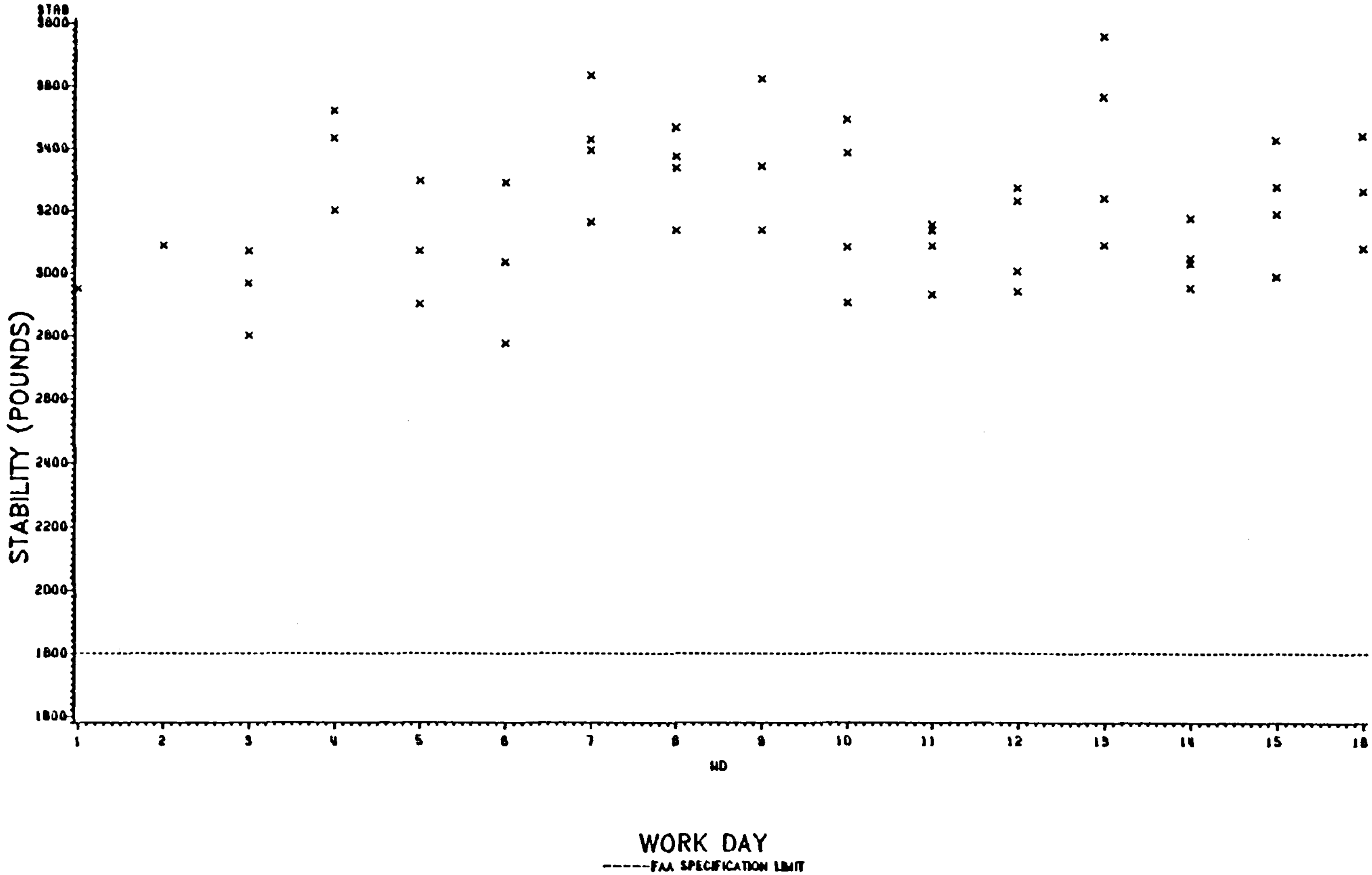

Figure 9. Rochester Stability versus Work Day

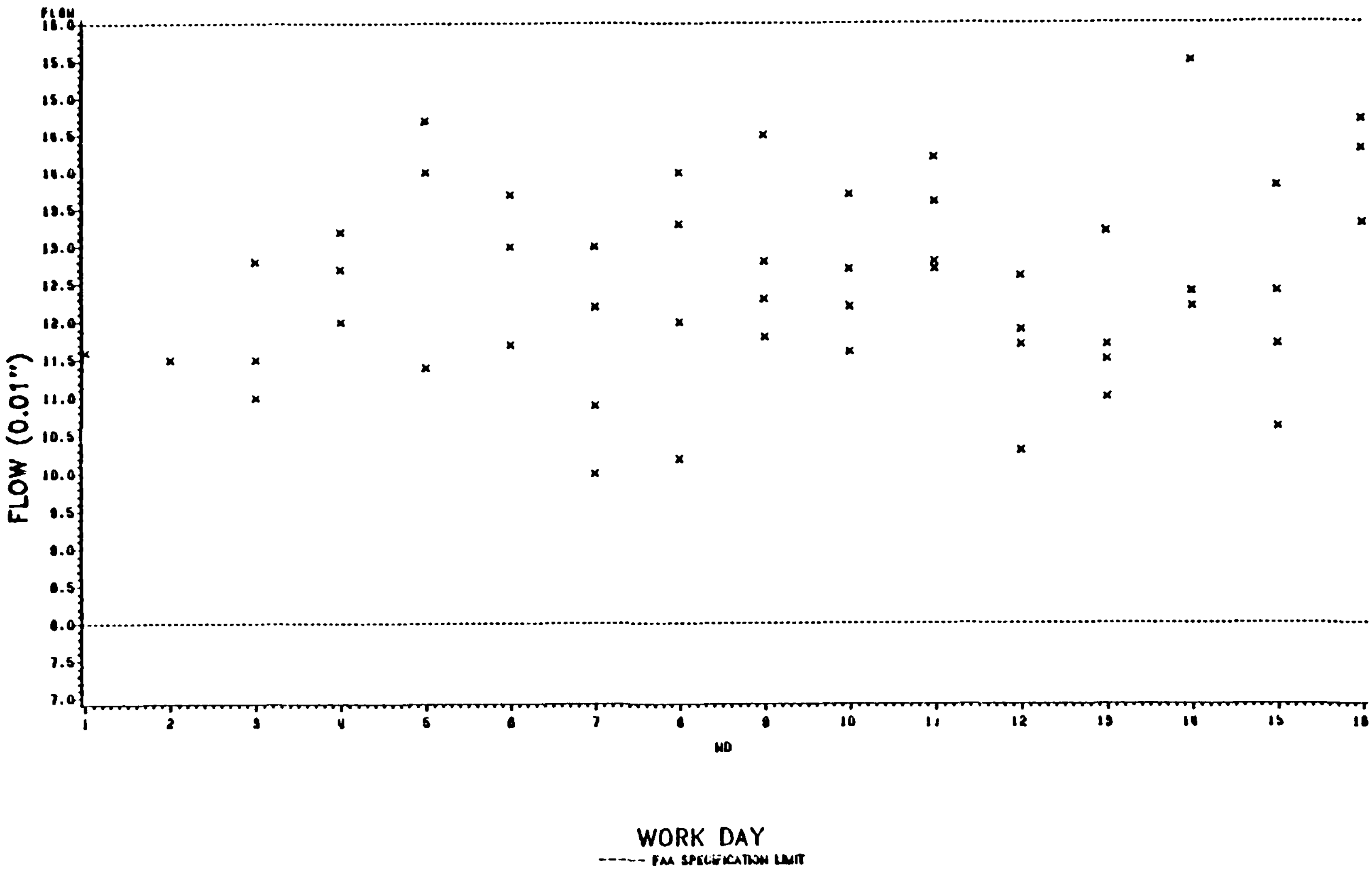

Figure 10. Rochester Flow versus Work Day

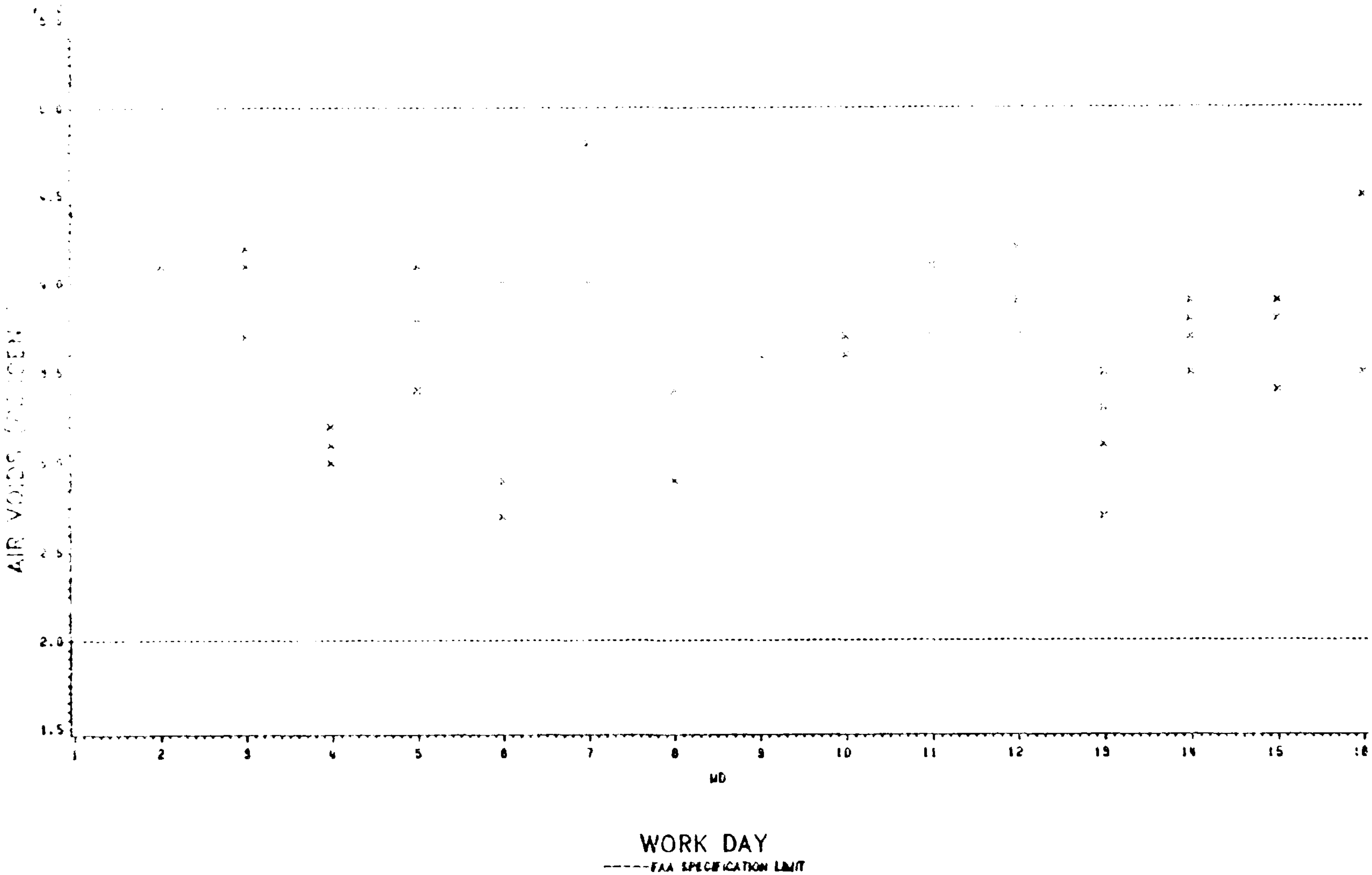

Figure 11. Rochester Air Voids versus Work Day

[illegible] Results

[illegible] resulting from data [illegible] presented in this [illegible] before a multiple [illegible] all 3 properties [illegible] relationships which exist among [illegible] if any correlations are found to [illegible] price adjustment plan.

[illegible] are discussed: the Marshall [illegible], the Marshall stability with [illegible] Marshall flow with air voids correlation. [illegible] coefficients between approximately 0.3 [illegible] to represent mild correlation, coefficients [illegible] 0.7 were considered to represent moderate [illegible] coefficients between 0.7 and 1.0 indicate a strong [illegible] investigated.

[illegible] analysis was conducted on the Marshall test results [illegible] among the 3 properties from day to day are [illegible] relationships. Correlation results for [illegible] Marshall flow, Marshall stability with air [illegible] with air voids, for the NAFEC, BWI, and [illegible] Table VII. Also included in Table VII [illegible] this correlation could be obtained if the [illegible] any 2 properties is zero.

[illegible] Results

[illegible] Table VII, the stability and flow correlation from [illegible] associated probability of 0.3296 of getting a [illegible] high if the true correlation is zero. Since [illegible], this indicates that the true correlation [illegible] the alpha = 0.05 level of significance. [illegible] from the Rochester project with a [illegible] and a probability of 0.5410. For the [illegible], the correlation coefficient is -0.5974, with a [illegible] is less than 0.05, the data [illegible] between stability and flow is not equal to [illegible] level, but suggest that a moderately negative correlation [illegible]

[illegible] the plots of flow versus work day for each [illegible] the Rochester and NAFEC projects, [illegible] (88%) were recorded as 10.0 or [illegible] BWI project may have had a [illegible] results and could account for the [illegible] and the coefficients resulting [illegible]

[illegible] BWI, and [illegible]

		Significance[a]	Observations
[illegible]	[illegible]	[illegible]	199
[illegible]	[illegible]	0.0001	199
[illegible]	[illegible]	0.0001	199
[illegible]	[illegible]	0.0001	67
[illegible]	[illegible]	0.0155	67
[illegible]	[illegible]	0.5446	67
[illegible]	[illegible]	0.5110	53
[illegible]	[illegible]	0.0907	53
[illegible]	[illegible]	0.4074	53

[illegible] least this correlation [illegible]

Table A-[illegible]

[illegible]	Stability ([illegible])	Flow (0.01")	Air Voids%	Lot
[illegible]	[illegible]	10.8	3.5	11
[illegible]	[illegible]	9.0	4.4	11
[illegible]	[illegible]	[illegible]	[illegible].8	11
[illegible]	[illegible]	[illegible]	4.[illegible]	12
[illegible]	[illegible]	[illegible]	3.5	12
[illegible]	[illegible]	[illegible]	[illegible].6	12
[illegible]	[illegible]	[illegible]	3.[illegible]	13
[illegible]	[illegible]	[illegible]	[illegible].6	13
[illegible]	[illegible]	[illegible]	2.[illegible]	13
[illegible]	[illegible]	[illegible]	[illegible].6	14
[illegible]	[illegible]	[illegible]	[illegible]	14
[illegible]	[illegible]	[illegible]	4.[illegible]	14
[illegible]	[illegible]	9.3	5.0	14
[illegible]	[illegible]	[illegible].7	2.8	15
[illegible]	[illegible]	[illegible]	4.4	15
[illegible]	[illegible]	[illegible]	4.4	15
[illegible]	[illegible]	9.[illegible]	5.4	15
[illegible]	[illegible]	[illegible].8	3.7	16
[illegible]	[illegible]	[illegible]	5.1	17
[illegible]	[illegible]	9.[illegible]	4.0	17
[illegible]	[illegible]	[illegible].0	3.7	17
[illegible]	[illegible]	8.[illegible]	3.7	17
[illegible]	[illegible]	[illegible].7	3.9	18
[illegible]	[illegible]	9.8	4.3	18
[illegible]	[illegible]	5.2	3.[illegible]	18
[illegible]	[illegible]	10.0	3.4	18
[illegible]	[illegible]	9.8	3.0	19
[illegible]	[illegible]	10.[illegible]	3.[illegible]	19
[illegible]	[illegible]	[illegible].8	3.3	19
[illegible]	[illegible]	[illegible].8	4.1	20
[illegible]	[illegible]	9.8	3.[illegible]	20
[illegible]	[illegible]	9.[illegible]	3.5	20
[illegible]	[illegible]	1[illegible].0	3.9	21
[illegible]	[illegible]	[illegible]	2.[illegible]	21
[illegible]	[illegible]	1[illegible]	2.9	21
[illegible]	[illegible]	[illegible]	2.3	21
[illegible]	[illegible]	10.0	3.0	22
[illegible]	[illegible]	10.0	3.3	22
[illegible]	[illegible]	[illegible].8	2.7	22
[illegible]	[illegible]	[illegible]	[illegible].7	23

Table A-I. NAFEC Marshall Test Data

Obs.	Stability (Lbs.)	Flow (0.01")	Air Voids%	Lot
1	2291	10.5	2.4	1
2	2393	9.0	2.7	1
3	2579	7.5	2.2	1
4	2415	9.0	3.6	1
5	2310	9.2	3.7	2
6	2360	8.8	3.3	2
7	2976	7.0	3.4	3
8	2489	7.8	3.8	3
9	2693	9.3	3.9	3
10	2232	8.8	3.9	4
11	2560	8.8	4.3	4
12	2525	9.3	3.4	4
13	2995	9.5	2.1	4
14	2111	8.7	4.4	5
15	2453	10.1	3.1	5
16	2841	10.8	3.2	5
17	2347	9.5	3.9	5
18	2460	10.0	3.7	6
19	2592	9.5	4.3	6
20	2296	8.5	3.7	6
21	2228	8.9	3.9	6
22	2278	8.7	4.2	7
23	2125	8.8	3.8	7
24	1970	9.5	4.0	7
25	2046	9.0	3.8	7
26	1986	10.3	3.5	8
27	2236	10.3	3.3	8
28	2525	11.9	2.1	8
29	2222	8.8	3.7	8
30	2530	11.5	1.5	9
31	2330	11.0	2.6	9
32	2754	11.6	1.8	9
33	2430	10.4	2.6	9
34	3227	11.7	2.0	9
35	2383	13.0	3.3	9
36	2144	12.2	3.5	10
37	2300	10.0	4.2	10
38	2540	10.1	3.7	10
39	2665	10.0	4.0	10
40	2388	10.0	4.5	11

Appendix A

[illegible] and Extraction Test Field Data

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2. Burati, J. L., and J. H. Willenbrock, Acceptance Criteria for Bituminous Surface Course on Civil Airport Pavements. Report No. FAA-RD-79-89. National Technical Information Service, 1979.

3. Laboratory Procedures Manual. Department of Transportation, Federal Aviation Administratioin: Eastern Region, 1981.

4. SAS User's Guide: Basics, 1982 Edition, SAS Institute Inc., Cary, NC, 1982.

Recommendations

The analyses of the field data were inconclusive with respect to correlations among the Marshall properties. The field data support the findings of the laboratory analysis (Volume 1) regarding negative correlations between stability and air voids and between flow and air voids. The results of the field data analysis, along with the laboratory results, indicate that it is not appropriate to consider the Marshall properties to be statistically independent. It is recommended that the correlation among the properties be considered when developing a multiple price adjustment approach for the Marshall properties. It is recommended that computer simulation be used to investigate methods for dealing with correlated multiple acceptance properties. The results of such analyses are presented in subsequent volumes of this report series.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

This research was conducted in response to an FAA-sponsored research project recomendation (2) concerning the implementation of a multiple price adjustment system using the Marshall properties: stability, flow, and air voids. Since the Marshall properties are determined from a single test it was reasonable to assume that they were statistically correlated. Before a multiple price adjustment plan could be developed it was necessary to identify any relationships to avoid penalizing the contractor twice for deficiencies in a single characteristic. Data were collected from 5 projects in the FAA Eastern Region during the 1981 construction season; however, only 3 were large enough to be included in the anlysis. Attempts were made to limit sampling and testing variability by conducting preconstruction meetings with all parties involved and stressing their importance in the data analysis.

The purpose of the field data analysis was to determine if statistical correlations existed among the Marshall properties and to develop mathematical equations to predict the Marshall properties from the extracted asphalt content and aggregate gradation.

Conclusions

The following conclusions were reached from the field results concerning the application of a multiple price adjustment system for the Marshall properties:

1. A statistically significant correlation exists among stability and air voids. The results suggest a moderately negative correlation.

2. No statistically significant correlation was identified between stability and flow.

3. The data suggest the possibility of a slight negative correlation between flow and air voids.

4. The Marshall properties can not be estimated with much predictive capability using the extracted asphalt content and aggregate gradations. Considerable variability is present in field sampling and testing.

Table XIII. Linear Regression Analysis using STEPWISE for Air Voids from NAFEC, BWI, and Rochester Projects

STEPWISE		
Data Source	Regression Equation	R^2
NAFEC	Void = 45.56-15.41(AC)-.39(S1/2)+.12(S4) +1.01(S50)+.40(S200)+1.04(AC)(AC) -0.12(AC)(S200)-0.20(AC)(S50) -0.01(AC)(S8)+0.09(AC)(S1/2)	0.311
BWI	Void = 2.84+0.02(S3/8)-0.02(S4)+0.04(S8) +0.11(S50)	0.243
ROCH	Void = 11.77-0.11(S1/2)+0.02(S1/4)-.02(S1/8) +.09)S20)-.11(S80)+.03(AC)(S200)	0.219

ROCH - Rochester Project
Void - Air Voids
AC - Asphalt Content
S1/2 - 1/2" Sieve
S#4 - #4 Sieve

Table XII. Linear Regression Analysis using GLM for Air Voids from NAFEC, BWI, and Rochester Projects

General Linear Model		
Data Source	Regression Equation	R^2
NAFEC	Void = -255.63+47.80(AC)+3.11(S3/4) -0.86(S1/2)+0.63(S3/8)-0.48(S4) +0.40(S8)+0.99(S50)+0.47(S200) +1/04(AC)(AC)-0.13(AC)(S200) -0.19(AC)(S50)-0.09(AC)(S8) +0.13(AC)(S4)-0.13(AC)(S3/8) +0.19(AC)(S1/2)-0.65(AC)(S3/4)	0.320
BWI	Void = -382.88+134.73(AC)+3.61(S1/2) -2.20(S3/8)-0.92(S4)-1.41(S8) +6.80(S16)-4.80(S30)-5.05(S50) -13.26(S100)+16.52(s200)-11.84(AC)(AC) -2.91(AC)(S200)+2.36(AC)(S100) +0.91(AC)(S50)+0.85(AC)(S30) -1.21(AC)(S16)+0.26(AC)(S8) +0.16(AC)(S4)+0.38(AC)(S3/8) -0.63(AC)(S1/2)	0.408
ROCH	Void = 43.39-5.84(AC)-0.48(S1/2) +0.53(S1/4)-0.18(S1/8)+0.73(S20) -2.06(S40)-0.22(S80)+0.29(S200) -0.10(AC)(AC)-0.02(AC)(S200) +0.02(AC)(S80)+0.33(AC)(S40) -0.10(AC)(S20)+0.03(AC)S1/8) -0.08(AC)(S1/4)+0.07(AC)(S1/2)	0.267

ROCH - Rochester Project
Void - Air Voids
AC - Asphalt Content
S1/4 - 1/4" Sieve
S#4 - #4 Sieve

Table XI. Linear Regression Analysis using STEPWISE for Flow from NAFEC, BWI, and Rochester Projects

STEPWISE		
Data Source	Regression Equation	R^2
NAFEC	Flow = -12.11+4.21(AC)+0.40(S4) +0.18(AC)(AC)-0.08(AC)(S4)-0.1(AC)(S4)	0.039
BWI	Flow = 4.75-0.18(S8)+0.27(S200) -0.01(AC)(S30)+0.03(AC)(S16) +0.01(AC)(S1/2)	0.170
ROCH	Flow = -17.95-0.26(S1/2)+0.06(S1/4) -0.27(S80)-0.34(S200)-0.01(AC,(S1/8)	0.291

ROCH - Rochester Project
Flow - Marshall Flow
AC - Asphalt Content
S1/4 - 1/4" Sieve
S#4 - #4 Sieve

Table X. Linear Regression Analysis using GLM for Flow from NAFEC, BWI, and Rochester Projects

General Linear Model		
Data Source	Regression Equation	R^2
NAFEC	Flow = 322.16-66.98(AC)-3.93(S3/4) +1.76(S1/2)-1.02(S3/8)+0.18(S4) +0.37(S8)-0.87(S50)-0.02(S200) -0.46(AC)(AC)+0.02(AC)(S200) +0.16(AC)(S50)-0.07(AC)(S8) -0.04(AC)(S4)+0.21(AC)(S3/8) -0.38(AC)(S1/2)+0.83(AC)(S3/4)	0.087
BWI	Flow = -198.96+145.50(AC)-4.24(S1/2) -3.02(S3/8)+5.87(S4)+12.2(S8) -26.87(S16)+16.16(S30)-7.81(S50) -14.66(S100)+23.55(s200)-19.39(AC)(AC) -4.12(AC)(S200)+2.54(ASC)(S100) +1.40(AC)(S50)-2.88(AC)(S30) +4.81(AC)(S16)-2.20(AC)(S8) -1.04(AC)(S4)+0.53(AC)(S3/8) +0.77(AC)(S1/2)	0.284
ROCH	Flow = -915.56+165.48(AC)+8.97(S1/2) +0.80(S1/4)-1.58(S1/8)-8.67(S20) +10.71(S40)-0.82(S80)+1.03(S200) -2.91(AC)(AC)-0.23(AC)(S200) +0.08(AC)(S80)-1.76(AC)(S40) +1.41(AC)(S20)+0.28(AC)S1/8) -0.12(AC)(S1/4)-1.44(AC)(S1/2)	0.380

ROCH - Rochester Project
Flow - Marshall Flow
AC - Asphalt Content
S1/2 - 1/2" Sieve
S#4 - #4 Sieve

Table IX. Linear Regression Analysis using STEPWISE for Stability from NAFEC, BWI, and Rochester Projects

STEPWISE		
Data Source	Regression Equation	R^2
NAFEC	Stab = 3289.6-25.2(S4)+136.4(S200)	0.139
BWI	Stab = 3168.9+21.4(S8)-8.2(AC)(S100) +1.6(AC)(S30)-4.1(AC)(S16) -0.8(AC)(S4)	0.192
ROCH	Stab = 142974.2-28924.8(AC)-1203.0(S1/2) +381.5(S40)+811.1(AC)(AC) -5.7(AC)(S200)-57.1(AC)(S40) -2.3(AC)(1/4)+208.5(AC)(S1/2)	0.318

ROCH - Rochester Project
Stab - Marshall Stability
AC - Asphalt Content
S1/2 - 1/2" Sieve
S#4 - #4 Sieve

Table VIII. Linear Regression Analysis using GLM for Stability from NAFEC, BWI, and Rochester Projects

General Linear Model		
Data Source	Regression Equation	R^2
NAFEC	Stab = -69021.1+15330.7(AC)+754.4(S3/4) +117.8(S1/2)-68.6(S3/8)-288.4(S4) +80.3(S8)-60.2(S50)+1246.5(S200) 19.4(AC)(AC)-232.6(AC)(S200) +14.9(AC)(S50)-18.2(AC)(S8) +56.6(AC)(S3/8)+13.7(AC)(S1/2) -160.6(AC)(S3/4)	0.164
BWI	Stab = 13340.3+4751.8(AC)-662.3(S1/2) +323.8(S3/8)-796.0(S4)-289.8(S8) +1202.0(S16)-1184.4(S30)+317.9(S50) +4283.0(S100)-1619.2(S200) -1165.1(AC)(AC)+285.2(AC)(S200) -760.1(AC)(S100)-59.5(AC)(S50) +211.0(AC)(S30)-217.2(AC)(S16) +55.7(AC)(S8)+139.3(AC)(S4) -57.1(AC)(S3/8)+117.9(AC)(S1/2)	0.333
ROCH	Stab = 222801.3-44565.9(AC)-2240.6(S1/2) +148.3(S1/4)+497.3(S1/8)+1697.1(S20) -1834.7(S40)-759.2(S80)+278.1(S200) -1164.3(AC)(AC)-52.6(AC)(S200) +126.4(AC)(S80)+316.1(AC)(S40) -286.4(AC)(S20)-83.7(AC)(S1/8) -26.4(AC)(S1/4)+383.8(AC)(S1/2)	0.441

ROCH - Rochester Project
Stab - Marshall Stability
AC - Asphalt Content
S3/4 - 3/4" Sieve
S#4 - #4 Sieve

[illegible] in the gradation. The GLM [illegible] all variables in developing the regression [illegible], while the STEPWISE procedure included only those variables that were significant at the 50 percent level.

[illegible]

[illegible] results of the GLM and [illegible] along with the resulting coefficient [illegible] the STEPWISE analysis, there is no [illegible] variables which entered the model at the 0.5 [illegible] regression produced higher R-squared [illegible] for each Marshall property [illegible] in the analysis. The BWI and [illegible] VIII and IX produced the highest [illegible] in predictive capabilities.

[illegible]

[illegible] results for flow from NAFEC, BWI, and [illegible] given in Tables X and XI along with the resulting [illegible] values. As with the stability analysis, there are no [illegible] among the variables entering the model from the STEPWISE [illegible] analyses. Although the GLM regression values are higher than [illegible] the STEPWISE regression, they are too low to be used for [illegible] properties.

[illegible]

[illegible] and STEPWISE regression results for air voids are given in Tables [illegible], respectively. Although the R-squared values are [illegible] consistent for the 3 projects, the variables entering [illegible] at the 0.5 level are again different. As with the [illegible], the equations are relatively low in predictive capabilities.

Stability and Air Voids Correlation Results

[illegible] of stability and air voids correlations from the NAFEC, BWI, and Rochester projects provided similar results. The correlation coefficient was [illegible] from NAFEC with the probability 0.0001. For the BWI project the correlation coefficient was -0.2945 with a probability of [illegible]. The coefficient from the Rochester project was also negative, [illegible], with the associated probability of [illegible] based on the test correlation. From the probabilities associated with the correlation coefficients, at the alpha = 0.05 level for the results from NAFEC and BWI, and at the alpha = 0.10 level for Rochester, the true correlation can be said to be different from zero. The consistent results, in fact, suggest that there is a slight to mild negative correlation between stability and air voids.

Flow and Air Voids Correlation Results

The NAFEC correlation analysis between flow and air voids resulted in a negative correlation coefficient of -0.3008. The probability of getting a correlation at least this high if the true correlation is zero is 0.0001. The BWI correlation on the other hand is 0.0753, with a related probability of 0.5446 indicating insufficient evidence to reject the null hypothesis that the true correlation is zero at the 5% level. From Rochester, the correlation coefficient is negative at -0.1162. The [illegible] probability indicates that the null hypothesis cannot be rejected at the 5% level since the probability was greater than 0.05. Although the BWI and Rochester analyses suggest no statistically significant difference from zero, the BWI correlation analysis for flow may be affected for the same reason mentioned in the stability and flow analysis. The NAFEC and Rochester results show that if there is a correlation between flow and air voids it is probably slightly negative.

Regression Results

In addition to the correlation analysis, the other objective of the field data research was an effort to develop predictive equations for estimating Marshall stability, flow, and air voids from the extracted asphalt content and aggregate gradations. At the request of the researcher and FAA Eastern Region, a portion of the sample taken for Marshall testing was also used for the contractor's extraction quality control test. So, for the purpose of this analysis, the Marshall test to determine stability, flow, and air voids, and the extraction test to determine the asphalt content and aggregate gradation were conducted on the same sample of material.

The statistical analysis was performed using the GLM and STEPWISE procedures in SAS [illegible] to investigate the cause and effect relationships between the extracted asphalt content and percentages of aggregate passing the various sieves and each of the Marshall properties. The list of variables used in the analysis includes: 1) the extracted asphalt content, 2) the extracted percentages of aggregate passing the various sieves [illegible], since a relationship exists between [illegible], 3) interaction terms, i.e., asphalt content [illegible], the asphalt content multiplied by the percent

Table A-I (Cont'd.)

Obs.	Stability (Lbs.)	Flow (0.01")	Air Voids%	Lot
81	2663	10.0	2.3	23
82	2518	9.2	2.3	23
83	2514	10.8	2.7	24
84	2892	10.8	2.5	24
85	2778	10.3	2.3	24
86	2658	9.2	3.2	24
87	2273	9.7	4.6	25
88	2637	10.0	3.9	25
89	2408	9.8	5.2	25
90	3245	10.2	3.4	25
91	2801	11.0	2.2	26
92	2694	10.7	2.0	26
93	3446	10.3	2.2	26
94	2947	9.8	1.9	26
95	2220	9.3	3.2	27
96	2135	9.8	3.4	27
97	2140	10.5	3.3	27
98	2275	10.0	3.7	27
99	2357	9.0	3.6	27
100	2453	9.5	4.7	28
101	2315	8.7	3.3	28
102	2347	9.7	2.9	28
103	2171	10.0	3.4	29
104	2391	9.5	2.7	29
105	3536	10.0	3.3	29
106	2240	10.8	3.5	29
107	2304	9.7	3.8	30
108	2450	9.8	3.1	30
109	2659	10.0	3.3	30
110	2229	10.7	3.5	30
111	2345	11.0	2.6	31
112	2380	10.5	2.7	31
113	2250	10.0	2.8	31
114	2368	9.7	2.4	31
115	2461	10.2	2.1	32
116	2368	9.5	2.9	32
117	2368	9.8	2.3	32
118	2372	10.7	3.2	32
119	2465	10.3	2.7	33
120	2368	9.7	2.8	33

Table A-1 (Continued)

[illegible]	Stability (lb)	Flow (0.01")	Air Voids, %	[illegible]
[illegible]	[illegible]	9.8	3.8	33
[illegible]	2131	9.8	4.6	33
[illegible]	[illegible]	[illegible]	4.3	34
124	[illegible]	11.0	[illegible]	34
[illegible]	[illegible]	10.7	3.9	34
[illegible]	[illegible]	9.8	3.8	34
[illegible]	[illegible]	10.7	3.5	35
[illegible]	[illegible]	10.7	3.1	35
[illegible]	[illegible]	10.0	4.3	35
[illegible]	[illegible]	10.0	4.5	35
[illegible]	2269	9.7	4.8	36
132	2438	10.2	3.4	36
133	2586	10.3	3.1	36
134	2267	11.0	4.5	36
135	2473	10.8	3.3	37
136	2414	9.8	3.7	37
137	2717	10.0	3.7	37
138	2564	9.8	3.5	37
139	2112	10.2	3.3	37
140	2307	9.3	4.9	38
141	2718	9.5	2.9	38
142	2174	9.7	4.4	38
143	2882	10.2	3.6	38
144	2650	10.2	2.8	39
145	2430	10.2	3.7	39
146	2429	10.2	4.5	39
147	[illegible]	11.2	3.7	39
148	2468	10.7	3.7	40
149	2067	11.5	2.8	40
150	2212	9.7	2.8	40
151	2157	9.2	2.8	40
152	2371	11.2	2.5	40
153	2137	10.7	2.3	41
154	2048	10.3	3.4	41
155	2273	9.0	2.9	41
156	2071	9.7	3.9	41
157	2027	10.5	3.0	41
158	2319	11.0	3.3	42
159	2688	10.2	3.0	42
160	2036	9.5	3.9	42

Table A-I (Cont'd.)

Obs.	Stability (Lbs.)	Flow (0.01")	Air Voids%	Lot
161	2309	10.3	3.6	42
162	2264	11.0	3.8	42
163	2491	11.2	2.7	43
164	2218	10.0	3.5	43
165	2445	10.3	3.1	43
166	2123	9.5	3.4	44
167	2252	10.3	3.3	44
168	2217	10.0	4.0	44
169	2303	9.7	3.1	44
170	2602	11.3	3.2	45
171	2413	9.5	4.1	45
172	2260	10.3	4.5	45
173	2549	11.2	3.5	45
174	2509	10.2	3.4	45
175	2637	9.5	3.5	45
176	2547	9.7	3.5	46
177	2476	10.8	2.8	46
178	2601	9.5	3.2	46
179	2425	10.5	3.3	46
180	2067	10.2	4.5	46
181	2578	11.0	2.4	47
182	2274	9.5	2.4	47
183	2574	11.2	3.7	47
184	2256	10.5	4.3	47
185	2736	10.8	3.4	47
186	2186	10.3	3.5	48
187	2403	10.3	3.6	48
188	2789	10.7	3.2	49
189	2627	9.5	3.3	49
190	2229	10.5	4.1	49
191	2194	10.2	4.2	49
192	2232	9.8	4.4	49
193	2461	10.8	4.6	50
194	2508	10.0	3.7	50
195	2205	10.2	3.8	50
196	2601	9.5	4.1	50
197	2543	9.7	3.9	51
198	2554	10.5	3.4	51
199	2438	10.3	3.3	51

Table A-II. BWI Marshall Test Data

Obs.	Stability (lbs.)	Flow (0.01")	Air Voids 3,% 1/	Lot
1	[illegible]	11.3	3.0	1
2	2817	10.7	2.9	1
3	2825	10.0	3.0	1
4	2917	10.3	3.1	1
5	2858	10.7	3.2	2
6	2825	10.3	3.1	2
7	2875	10.7	3.0	2
8	2925	10.0	3.2	2
9	2808	11.0	3.5	3
10	2883	10.0	3.3	3
11	2783	10.0	3.7	3
12	2700	11.0	3.2	3
13	2650	12.0	3.6	4
14	2775	11.0	3.3	4
15	2675	11.0	3.2	4
16	2725	11.0	3.3	4
17	2825	10.0	3.7	5
18	2758	11.0	3.5	5
19	2883	10.0	3.4	5
20	2767	10.0	3.7	5
21	2725	11.0	3.5	6
24	2775	11.0	3.3	6
23	2700	11.0	3.4	6
24	2842	10.0	3.2	6
25	2733	10.0	3.5	7
26	2758	10.0	3.4	7
27	2717	11.0	3.5	7
28	2725	10.0	3.7	7
29	2800	11.0	3.6	8
30	2792	10.0	3.5	8
31	2742	11.0	3.3	9
32	2792	11.0	3.4	9
33	2925	10.0	3.2	9
34	2842	10.0	3.3	9
35	2717	11.0	3.2	10
36	2833	10.0	3.2	10
37	2717	10.0	3.5	10
38	2733	11.0	[illegible]	10
39	2808	10.0	3.4	11
40	2875	10.0	3.6	11

Table A-II (Cont'd.)

Obs.	Stability (Lbs.)	Flow (0.01")	Air Voids%	Lot
41	2758	11.0	3.4	11
42	2742	11.0	3.6	11
43	2842	10.0	3.4	12
44	2725	11.0	3.6	12
45	2750	11.0	3.5	12
46	2833	11.0	3.8	13
47	2842	11.0	3.6	14
48	2775	11.0	3.7	14
49	2750	12.0	3.4	14
50	2933	10.0	3.5	15
51	2767	11.0	3.8	15
52	2733	11.0	3.4	15
53	2767	11.0	3.6	15
54	2742	11.0	3.3	16
55	2808	11.0	3.5	16
56	2692	11.0	3.4	16
57	2875	10.0	3.2	16
58	2842	10.0	3.5	17
59	2808	10.0	3.3	17
60	2733	11.0	3.5	17
61	2858	10.0	3.2	17
62	2800	11.0	3.4	18
63	2758	11.0	3.5	18
64	2867	10.0	3.5	18
65	2708	11.0	3.6	18
66	2858	10.0	3.4	19
67	2783	10.0	3.7	19

Table A-III Rochester Marshall Test Data

Obs	Stability (lbs.)	Flow (0.01")	Air Voids%	Lot
1	[illegible]	11.5	4.4	1
2	[illegible]	11.5	4.1	2
3	[illegible]	12.8	3.7	3
4	2802	11.5	4.1	3
5	2070	11.0	4.2	3
6	[illegible]	12.7	3.2	4
7	3522	13.2	3.1	4
8	[illegible]	12.0	3.0	4
9	3237	11.4	4.1	5
10	3073	14.7	3.8	5
11	2902	14.0	3.4	5
12	3038	11.7	2.7	6
13	3293	13.7	2.9	6
14	2778	13.0	4.0	6
15	3138	10.0	4.8	7
16	3430	10.9	3.9	7
17	3635	12.2	4.0	7
18	3396	13.0	4.0	7
19	3467	14.0	3.5	8
20	3137	10.2	3.4	8
21	3375	13.3	3.6	8
22	3338	12.0	2.9	8
23	3374	12.8	3.6	9
24	3346	14.5	3.6	9
25	3140	12.3	3.6	9
26	3344	11.8	3.4	9
27	3494	13.7	3.6	10
28	3084	12.7	3.6	10
29	3388	12.2	3.7	10
30	2907	11.6	3.6	10
31	2935	13.6	4.1	11
32	3031	12.8	3.7	11
33	3140	12.7	3.9	11
34	3158	14.2	3.7	11
35	3028	12.6	3.9	12
36	2943	11.9	3.7	12
37	3274	10.3	4.2	12
38	3233	11.7	4.2	12
39	3365	11.7	3.5	13
40	3091	11.0	3.3	13

Table A-III (Cont'd.)

Obs.	Stability (Lbs.)	Flow (0.01")	Air Voids%	Lot
41	3758	13.2	3.1	13
42	3241	11.5	2.7	13
43	3030	12.2	3.9	14
44	2952	15.5	3.5	14
45	3174	12.2	3.7	14
46	3047	12.4	3.8	14
47	3187	10.6	3.9	15
48	3276	11.7	3.8	15
49	2987	12.4	3.4	15
50	3426	13.8	3.4	15
51	3078	14.3	4.5	16
52	3437	14.7	4.5	16
53	3259	13.3	3.5	16

Table A-IV. NAFEC Extraction Test Data

Obs	AC	Percent Passing Sieve 1"	3/4	1/2	3/8	#4	#8	#50	#200	Lot
1	5.0	100.	100.	87.2	78.6	52.6	37.6	14.8	3.4	1
2	5.0	100.	98.9	89.5	80.4	52.6	37.5	14.5	4.7	1
3	4.9	100.	99.2	86.2	75.6	47.5	33.1	11.1	4.9	1
4	4.9	100.	100.	91.7	84.4	58.8	43.7	16.3	5.7	1
5	.	.	.	.	.	.	.	.	.	2
6	.	.	.	.	.	.	.	.	.	2
7	4.8	100.	99.1	97.4	89.3	55.4	35.5	14.1	5.0	3
8	5.2	100.	98.9	91.8	86.5	60.8	44.8.	16.8	6.0	3
9	4.9	100.	100.	95.1	88.7	60.7	42.2	16.1	5.7	3
10	5.2	100.	100.	96.6	89.7	62.0	45.3	16.6	5.9	4
11	.	.	.	.	.	.	.	.	.	4
12	5.6	100.	100.	97.2	90.9	71.5	54.7	19.4	6.7	4
13	4.7	100.	100.	95.6	89.6	60.6	42.1	17.9	7.0	4
14	4.7	100.	98.1	93.5	87.5	62.5	45.4	16.7	5.7	5
15	4.8	100.	100.	90.1	84.1	57.9	41.4	15.8	5.8	5
16	4.9	100.	100.	94.2	88.2	62.7	43.9	15.3	5.6	5
17	4.7	100.	100.	91.9	84.2	60.6	43.1	16.0	5.5	5
18	4.9	100.	100.	93.5	87.1	57.8	40.0	14.8	4.9	6
19	5.9	100.	100.	95.0	86.9	60.4	42.8	15.4	4.9	6
20	4.8	100.	100.	93.8	88.9	63.4	44.7	16.2	5.3	6
21	4.8	100.	100.	90.7	85.3	62.2	45.1	16.2	5.1	6
22	4.7	100.	100.	92.9	87.0	61.8	42.7	15.8	5.5	7
23	5.4	100.	100.	96.8	87.9	62.4	43.9	15.4	4.9	7
24	5.2	100.	100.	94.8	88.0	63.2	44.9	16.2	5.6	7
25	5.2	100.	100.	97.6	87.0	59.1	41.4	15.2	5.0	7
26	4.9	100.	100.	92.4	85.7	60.0	42.9	16.0	5.7	8
27	5.2	100.	99.1	93.7	88.4	63.5	46.9	16.7	6.0	8
28	4.8	100.	98.6	85.0	71.6	53.7	42.0	16.3	4.9	8
29	4.8	100.	100.	93.0	84.1	57.4	41.7	15.5	5.2	8
30	5.4	100.	100.	92.2	85.9	59.1	41.0	16.5	6.0	9
31	5.2	100.	100.	95.5	88.6	61.2	43.6	15.7	5.6	9
32	4.8	100.	100.	91.7	84.2	54.7	40.7	15.5	5.7	9
33	5.1	100.	100.	93.9	89.0	61.0	44.7	17.4	6.0	9
34	5.1	100.	100.	93.2	84.5	57.3	42.8	17.0	5.8	9
35	5.4	100.	100.	92.0	84.4	59.0	42.6	15.9	5.3	9
36	4.9	100.	100.	91.8	85.4	58.9	42.7	17.0	6.2	10
37	4.7	100.	99.5	90.8	83.4	55.9	41.1	15.7	5.6	10
38	4.7	100.	100.	93.8	88.5	64.2	46.3	17.9	6.0	10
39	4.5	100.	100.	93.9	88.3	60.2	44.2	17.6	5.9	10
40	4.6	100.	98.8	92.2	85.2	59.2	44.1	17.0	5.9	11

Table A-IV (Cont'd.)

Obs	AC	Percent Passing Sieve 1"	3/4	1/2	3/8	#4	#8	#50	#200	Lot
41	5.2	100.	100.	96.1	90.9	67.2	49.5	18.2	6.5	11
42	4.8	100.	100.	96.8	88.7	65.0	48.1	18.6	6.5	11
43	4.7	100.	100.	93.1	87.3	62.9	47.4	16.5	5.7	11
44	4.6	100.	100.	91.0	85.2	60.9	44.9	16.0	5.5	12
45	4.7	100.	100.	93.2	82.6	55.9	38.7	15.5	5.6	12
46	5.0	100.	100.	94.4	86.6	62.2	45.0	17.3	6.1	12
47	5.0	100.	100.	92.5	84.3	60.7	43.2	16.2	5.7	12
48	5.4	100.	100.	91.5	82.4	57.6	40.6	16.5	6.1	13
49	5.3	100.	100.	93.2	86.5	62.0	44.5	18.7	7.4	13
50	4.7	100.	100.	89.9	81.3	52.8	36.0	15.5	5.9	14
51	4.5	100.	98.1	91.5	82.1	53.8	38.1	15.6	6.0	14
52	4.6	100.	100.	93.8	86.3	61.1	43.9	17.4	5.9	14
53	4.7	100.	100.	94.2	89.1	63.2	47.2	16.8	5.7	14
54	4.5	100.	100.	85.6	74.3	47.7	34.2	14.5	5.3	15
55	4.3	100.	98.8	91.7	85.0	57.1	42.1	15.9	5.6	15
56	4.6	100.	100.	94.3	85.0	54.0	38.8	15.0	4.9	15
57	4.6	100.	98.6	91.1	84.7	61.9	47.3	16.4	5.4	15
58	4.8	100.	100.	99.1	93.2	59.9	41.9	15.2	5.0	16
59	4.9	100.	99.0	97.3	93.6	65.9	45.9	16.4	5.2	17
60	5.0	100.	100.	92.1	86.4	65.0	48.0	17.8	5.8	17
61	4.7	100.	100.	88.6	77.9	57.5	42.2	15.6	5.0	17
62	4.9	100.	100.	90.9	86.8	65.7	47.7	16.6	5.2	17
63	4.7	100.	100.	94.9	88.1	62.1	43.1	16.7	5.7	18
64	4.7	100.	100.	92.8	88.9	64.1	44.7	17.0	5.6	18
65	4.6	100.	100.	90.1	81.5	57.4	40.7	15.9	5.6	18
66	4.9	100.	100.	89.4	83.6	56.5	39.2	15.8	5.5	18
67	5.1	100.	100.	92.2	84.0	59.5	42.4	15.8	5.5	19
68	4.9	100.	98.9	94.6	87.2	61.3	42.9	16.1	5.7	19
69	4.8	100.	100.	90.2	85.1	60.2	42.6	17.1	5.6	19
70	4.7	100.	99.2	89.2	78.6	50.7	36.0	14.9	5.3	20
71	5.0	100.	100.	94.8	86.4	61.2	44.1	16.7	5.7	20
72	4.8	100.	100.	94.0	86.5	59.1	43.1	15.3	5.2	20
73	5.0	100.	100.	95.5	87.5	60.8	43.5	15.9	5.5	21
74	5.0	100.	100.	91.8	86.2	59.4	41.2	16.2	6.3	21
75	5.0	100.	100.	92.8	87.8	63.8	45.8	16.3	6.3	21
76	4.6	100.	97.0	90.5	83.6	57.1	40.8	15.1	5.6	21
77	5.0	100.	99.0	91.9	84.6	57.3	41.6	16.3	5.8	22
78	4.9	100.	100.	93.5	87.6	62.4	45.1	17.2	6.0	22
79	4.8	100.	100.	87.0	77.7	53.4	38.6	14.7	4.8	22
80	5.3	100.	98.9	92.5	88.0	62.5	44.0	16.7	5.2	23

Table A-IV (Cont'd)

Obs	AC	Percent Passing Sieve 1"	3/4	1/2	3/8	#4	#8	#50	#200	Lot
81	4.7	100.	98.9	86.6	79.8	55.8	40.1	15.6	5.3	23
82	5.0	100.	100.	93.9	85.8	58.4	42.7	16.2	5.3	23
83	[illegible]	100.	100.	94.9	86.9	61.3	43.2	15.8	5.7	24
84	4.9	100.	100	95.0	87.2	59.2	41.7	15.9	5.6	24
85	5.0	100.	98.5	92.2	84.0	58.1	42.1	16.6	6.0	24
86	4.9	100.	100.	93.1	85.6	57.9	42.2	15.8	5.2	24
87	4.5	100.	100.	93.6	86.8	60.3	43.0	16.4	5.6	25
88	4.5	100.	98.5	86.3	80.4	56.6	40.1	15.0	5.0	25
89	4.7	100.	100.	95.4	89.5	64.0	46.8	16.4	5.5	25
90	4.7	100.	98.8	88.1	78.1	55.5	39.2	12.8	4.6	25
91	4.5	100	100	88.6	77.5	54.0	40.2	13.9	4.8	26
92	5.[illegible]	100.	100.	91.1	85.5	61.9	44.7	15.9	5.0	26
93	4.[illegible]	100.	100.	90.6	82.9	54.2	39.1	14.6	5.1	26
94	4.8	100	100.	90.1	84.3	59.5	42.9	15.0	4.8	26
95	4.9	100	100.	92.5	86.0	59.8	42.7	14.5	4.6	27
96	[illegible]	[illegible]	[illegible]	95.4	88.8	63.4	47.3	15.3	4.9	27
97	[illegible].9	100.	100.	90.9	88.2	61.0	45.3	15.3	5.2	27
98	[illegible].4	100.	100.	93.3	88.9	64.5	52.9	15.2	4.5	27
99	4.[illegible]	100.	98.2	90.7	84.0	60.1	44.5	14.7	4.5	27
100	4.4	100.	100.	91.6	85.2	61.9	45.9	15.8	5.2	28
101	[illegible].5	100.	100.	91.0	85.6	62.4	44.9	13.7	4.9	28
102	4.9	100.	100.	94.3	88.8	62.3	43.2	13.4	4.7	28
103	5.0	100.	100.	95.3	88.3	64.1	44.9	14.1	4.1	29
104	5.0	100.	100.	92.7	86.0	64.9	54.4	13.8	4.6	29
105	4.9	100.	100.	92.9	85.9	61.8	43.7	14.1	4.8	29
106	4.[illegible]	100.	100.	94.8	88.2	62.6	56.6	15.6	4.2	29
107	4.7	100.	100.	93.2	88.2	65.4	47.6	15.4	4.6	30
108	4.5	100.	100.	94.3	88.6	64.3	46.1	14.8	4.7	30
109	4.6	100.	100.	89.7	80.8	56.0	41.3	14.8	5.4	30
110	[illegible]	100	98.0	89.4	82.8	61.8	45.5	15.3	5.0	30
111	4.8	100	100.	92.9	83.5	57.5	41.0	14.2	4.4	31
112	5.1	100.	100.	95.6	88.7	63.3	44.3	14.4	4.2	31
113	4.7	100.	99.7	92.7	83.1	51.9	35.5	9.4	2.1	31
114	4.7	100.	100.	89.7	81.0	55.4	38.7	12.9	4.1	31
115	4.6	100.	100.	96.2	86.7	58.7	42.1	16.2	5.3	32
116	4.8	100.	100.	92.9	88.7	63.2	46.6	17.5	5.7	32
117	4.5	100.	98.7	90.5	80.1	54.4	34.1	13.5	4.2	32
118	4.7	100.	98.1	93.2	83.5	59.8	45.3	16.9	5.1	32
119	4.3	100.	100.	94.4	86.4	62.8	52.4	16.3	4.7	33
120	4.7	100.	99.3	91.2	84.7	57.0	41.5	16.2	5.0	33

Table A-IV (Cont'd.)

Obs	AC	Percent Passing Sieve 1"	3/4	1/2	3/8	#4	#8	#50	#200	Lot
121	4.8	100.	100.	93.0	86.4	62.5	45.7	16.5	5.1	33
122	4.7	100.	100.	94.3	87.4	63.2	45.8	16.6	4.8	33
123	4.7	100.	100.	94.2	88.1	66.1	48.5	17.4	5.5	34
124	4.8	100.	100.	96.2	90.7	63.6	43.6	16.4	5.7	34
125	4.6	100.	100.	94.8	87.5	60.5	43.0	15.9	5.2	34
126	4.8	100.	100.	95.6	89.2	63.6	45.5	16.6	5.5	34
127	4.6	100.	99.1	91.0	85.1	61.4	44.2	14.8	4.1	35
128	4.9	100.	100.	91.8	85.0	59.4	41.5	14.0	4.5	35
129	5.1	100.	100.	90.7	85.5	63.8	45.8	14.8	5.1	35
130	4.9	100.	98.5	95.4	90.3	65.6	44.9	14.0	4.2	35
131	4.7	100.	100.	94.2	88.2	58.8	41.2	15.2	4.8	36
132	4.7	100.	99.2	93.9	87.0	59.6	41.8	14.9	5.0	36
133	4.7	100.	100.	90.7	85.1	61.4	44.0	16.2	5.3	36
134	4.7	100.	100.	92.0	86.7	62.6	44.5	15.8	5.1	36
135	5.0	100.	100.	93.2	86.4	63.0	45.9	16.5	5.4	37
136	5.0	100.	100.	93.2	86.8	63.5	46.8	16.8	5.4	37
137	4.7	100.	100.	91.4	77.4	60.2	44.4	16.0	5.5	37
138	4.6	100.	99.0	91.5	83.2	58.9	43.5	15.1	5.2	37
139	4.6	100.	100.	93.5	83.9	57.4	41.0	14.8	4.9	37
140	4.6	100.	100.	87.8	83.4	57.9	41.8	14.4	4.8	38
141	4.9	100.	100.	96.2	89.2	62.0	44.5	15.1	5.1	38
142	4.8	100.	100.	97.6	90.5	63.0	45.2	15.0	5.1	38
143	4.5	100.	99.3	94.9	89.1	62.6	44.2	15.1	5.1	38
144	4.9	100.	100.	93.1	85.3	59.2	42.0	14.3	5.0	39
145	5.1	100.	100.	95.6	89.7	65.0	46.3	15.5	5.4	39
146	4.7	100.	100.	97.4	90.3	62.8	42.5	13.0	4.6	39
147	4.8	100.	100.	95.4	88.3	60.6	43.6	13.7	4.9	39
148	4.8	100.	99.0	94.3	90.7	63.7	44.9	14.7	5.3	40
149	5.2	100.	100.	94.1	88.5	62.7	45.7	15.4	6.1	40
150	4.9	100.	100.	93.3	84.6	62.4	45.2	15.0	5.4	40
151	4.6	100.	100.	90.3	80.8	57.3	41.2	14.5	5.2	40
152	4.5	100.	100.	90.6	84.3	57.9	42.2	17.4	6.3	40
153	5.0	100.	100.	95.5	87.3	64.3	46.0	15.3	5.5	41
154	4.6	100.	100.	92.5	83.1	57.9	42.5	14.7	5.5	41
155	4.9	100.	100.	93.9	86.4	59.9	43.4	14.7	5.4	41
156	4.9	100.	100.	95.3	89.1	63.6	45.4	14.9	5.2	41
157	4.6	100.	97.4	92.4	86.2	61.8	44.5	15.2	5.2	41
158	4.6	100.	98.6	84.6	77.0	55.9	40.0	13.2	4.7	42
159	4.7	100.	100.	91.2	84.8	61.7	44.7	13.8	4.8	42
160	4.6	100.	100.	93.5	87.5	62.2	44.7	14.8	5.6	42

Table A-IV (Cont'd.)

Obs	AC	Percent Passing Sieve 1"	3/4	1/2	3/8	#4	#8	#50	#200	Lot
161	4.6	100.	100.	93.0	86.7	57.7	41.2	12.8	4.7	42
162	4.7	100.	100.	90.3	85.0	62.8	44.5	13.8	5.0	42
163	5.0	100.	99.0	83.8	75.1	56.5	42.5	14.6	5.6	43
164	4.8	100.	100.	89.5	83.5	58.5	41.5	13.5	4.9	43
165	4.5	100	100.	89.5	81.6	55.9	38.8	13.0	4.5	43
166	4.7	100.	100.	89.9	82.4	57.0	41.2	13.0	4.7	44
167	4.8	100.	100.	92.5	86.5	60.0	41.9	13.9	5.3	44
168	4.7	100.	100.	93.4	86.0	62.3	43.0	14.7	5.1	44
169	4.6	100.	98.7	91.4	86.0	59.4	42.4	14.4	5.4	44
170	4.8	100.	98.8	91.2	85.6	60.9	43.2	14.5	4.8	45
171	4.7	100.	100.	90.5	83.3	60.2	43.1	15.6	5.0	45
172	4.8	100.	100.	94.9	87.0	59.2	42.5	14.8	4.5	45
173	4.5	100.	100.	94.8	88.1	62.2	44.6	15.3	5.6	45
174	4.6	100.	98.7	92.5	87.1	63.3	45.6	14.6	5.6	45
175	4.6	100.	99.5	94.5	85.5	62.5	44.5	14.5	5.6	45
176	4.5	100.	100.	93.6	85.9	59.9	43.3	14.0	5.1	46
177	5.0	100.	100.	92.5	87.3	62.8	44.8	15.0	5.2	46
178	5.1	100.	100.	96.7	90.9	63.4	44.2	13.9	4.8	46
179	4.9	100.	100.	90.3	84.0	57.6	40.7	13.2	4.3	46
180	4.6	100.	100.	98.9	84.7	58.9	42.8	13.4	4.3	46
181	4.8	100.	100.	90.4	81.0	53.8	38.8	14.1	5.1	47
182	4.8	100.	99.3	93.4	87.5	59.9	43.1	15.1	5.1	47
183	4.8	100.	99.2	93.2	86.5	61.9	43.5	14.4	5.4	47
184	4.8	100.	100.	92.2	86.3	62.5	42.8	14.5	4.9	47
185	4.8	100.	98.3	94.4	86.8	61.0	41.4	14.5	5.2	47
186	4.9	100.	99.1	92.6	85.2	59.3	41.5	14.4	5.6	48
187	4.7	100.	100.	96.8	90.2	62.5	43.2	13.3	5.2	48
188	4.6	100.	100.	92.3	85.0	59.7	41.6	13.8	5.5	49
189	4.7	100.	100.	92.6	83.9	59.3	41.6	12.9	4.8	49
190	4.7	100.	100.	92.0	84.3	59.9	43.1	13.8	5.0	49
191	4.8	100.	100.	93.4	88.3	64.4	45.3	14.2	5.3	49
192	4.8	100.	100.	92.5	87.2	62.6	44.7	14.1	4.9	49
193	4.8	100.	100.	95.7	89.4	65.0	46.0	14.5	5.1	50
194	4.8	100.	100.	93.2	87.5	61.6	44.8	14.5	5.1	50
195	4.8	100.	100.	92.9	86.5	61.7	44.4	14.0	4.7	50
196	4.6	100.	100.	90.6	84.9	59.3	43.3	14.8	4.7	50
197	4.9	100.	100.	89.3	82.3	57.7	40.9	13.8	5.1	51
198	4.9	100.	100.	94.0	86.2	61.4	44.2	14.6	5.2	51
199	4.9	100.	100.	96.3	89.8	63.3	45.3	15.4	5.6	51

Table A-V. BWI Extraction Test Data

Obs	AC	Percent Passing Sieve 1/2	3/8	#4	#8	#16	#30	#50	#100	#200
1	5.7	91.7	81.1	62.7	50.1	41.4	32.0	18.0	9.9	5.3
2	5.5	.	.	.	.	.	.	.	.	
3	5.7	93.3	80.6	63.7	50.1	40.8	31.0	17.7	10.0	5.4
4	5.6	.	.	.	.	.	.	.	.	
5	5.7	92.9	83.4	64.4	51.4	42.9	33.8	19.0	10.5	5.8
6	5.6	92.4	82.1	62.7	50.1	41.5	32.8	18.0	9.8	5.4
7	5.7	94.1	85.8	66.6	53.8	44.5	34.6	19.7	11.3	6.5
8	5.6	93.5	85.3	65.5	52.9	44.1	34.8	19.4	10.9	6.3
9	5.7	95.5	86.4	67.7	53.7	43.7	33.7	19.8	11.2	6.2
10	5.7	95.8	87.5	68.8	53.7	44.8	35.9	20.2	11.0	6.0
11	5.7	91.8	80.5	60.2	50.9	40.6	31.0	19.5	10.7	5.8
12	5.6	94.1	84.3	65.9	51.6	42.5	34.7	19.6	10.8	5.6
13	5.6	94.5	84.6	67.0	53.8	44.4	34.5	20.0	11.2	6.3
14	5.7	94.4	85.2	66.6	52.9	43.9	34.8	19.9	10.5	6.6
15	5.7	93.4	83.5	65.6	52.1	43.1	33.7	19.2	10.6	6.1
16	5.5	91.0	80.4	60.7	48.9	41.0	32.5	18.3	10.1	5.6
17	5.5	93.0	79.7	59.9	48.7	40.5	32.2	17.7	9.9	5.3
18	5.6	93.9	84.7	65.1	51.7	42.9	33.9	19.2	10.7	5.9
19	5.6	93.7	82.4	62.4	51.7	42.3	33.7	18.6	11.3	5.6
20	5.7	93.0	84.1	68.5	54.3	45.0	36.7	21.5	11.5	6.5
21	5.6	94.1	84.5	65.3	52.1	43.5	34.5	19.9	11.3	6.3
22	5.7	93.5	83.3	65.1	52.2	43.3	34.2	19.7	10.8	6.3
23	5.6	93.0	83.0	64.4	51.1	47.6	33.7	18.1	10.2	5.5
24	5.5	91.7	78.5	62.0	49.1	40.7	32.2	18.6	10.7	6.0
25	5.7	91.4	83.7	66.2	51.5	41.9	32.4	18.9	10.8	6.2
26	5.6	91.9	84.5	67.0	51.8	42.6	31.8	18.5	10.6	6.1
27	5.6	92.8	85.3	66.8	53.1	44.1	35.1	20.3	11.7	7.0
28	5.7	95.3	86.1	67.8	54.5	45.8	36.4	20.2	11.3	6.3
29	5.7	94.3	84.4	67.2	54.0	44.7	34.9	19.6	11.1	6.5
30	5.5	93.9	83.1	62.9	49.9	41.0	32.1	18.8	10.8	6.2
31	5.6	94.8	84.8	64.1	50.4	41.3	32.6	18.5	10.1	5.4
32	5.6	94.3	84.0	63.5	50.1	41.0	32.0	18.2	10.3	5.5
33	5.7	94.7	84.1	63.5	49.4	40.6	31.8	18.3	10.3	5.6
34	5.6	93.2	84.1	62.6	49.0	41.2	31.4	18.9	10.5	5.5
35	5.6	94.3	84.9	64.7	50.6	41.2	32.1	18.3	10.8	6.1
36	5.5	94.8	85.2	65.0	51.0	42.5	33.9	19.0	11.0	6.3
37	5.7	93.9	84.6	68.0	53.7	43.9	34.1	19.5	10.8	5.9
38	5.6	92.0	83.6	64.1	49.0	41.0	32.2	18.6	10.6	6.0
39	5.7	94.8	85.9	70.3	57.3	45.7	35.0	19.7	10.2	6.0
40	5.6	90.9	78.9	61.7	50.3	41.4	32.5	18.6	10.5	5.7

Table A-V (Cont'd.)

Obs	AC	Percent Passing Sieve 1/2	3/8	#4	#8	#16	#30	#50	#100	#200
41	5.7	92.4	85.1	54.6	49.7	41.5	31.7	17.4	10.7	6.1
42	5.7	94.3	81.2	62.0	49.6	40.9	32.0	18.5	10.3	5.7
43	5.7	93.2	80.5	59.7	50.8	40.6	32.4	18.8	10.7	5.8
44	5.[illegible]	94.3	87.4	67.8	54.0	45.2	36.3	20.7	10.7	5.6
45	5.[illegible]	93.4	80.2	61.0	48.7	40.6	32.3	18.8	10.7	6.1
46	5.6	92.5	81.4	60.3	49.7	40.6	32.8	19.4	10.9	6.2
47	5.5	92.2	79.7	59.6	48.1	40.6	31.2	18.6	10.6	5.9
48	5.7	96.1	87.5	69.4	54.7	45.1	35.4	20.2	10.7	5.6
49	5.7	94.8	85.2	66.6	53.1	44.0	33.9	19.6	10.9	5.8
50	5.5	90.9	79.3	60.2	49.8	41.3	31.4	18.6	10.5	5.7
51	5.7	91.8	80.6	61.9	51.2	42.0	32.4	19.5	10.8	5.9
52	5.[illegible]	94.5	80.0	64.0	51.8	43.9	35.7	20.7	11.2	6.0
53	5.6	93.2	82.1	62.8	50.3	42.4	33.3	20.1	10.9	6.0
54	5.7	91.[illegible]	83.0	61.7	50.6	42.4	30.9	18.8	10.8	5.9
55	5.6	93.[illegible]	85.7	67.[illegible]	49.8	41.6	31.5	19.5	11.1	6.2
56	[illegible]	93.[illegible]	85.6	67.1	53.7	44.3	34.8	20.6	11.3	6.1
57	5.6	92.[illegible]	84.7	65.2	52.4	43.0	33.6	19.2	10.9	6.0
58	5.6	94.1	86.8	62.9	50.1	42.8	33.6	20.2	11.2	6.1
59	5.6	92.5	84.2	60.5	50.9	41.4	32.3	19.8	10.8	5.9
60	5.7	91.9	83.7	61.2	51.6	42.8	33.1	20.5	11.0	6.1
61	5.6	92.7	80.6	60.8	48.2	40.3	32.5	19.7	10.8	5.7
62	5.7	92.9	80.5	61.3	51.8	41.0	30.8	19.2	10.8	5.9
63	5.6	91.4	80.5	61.1	48.6	40.5	32.4	19.5	11.1	6.1
64	5.6	91.7	82.0	60.6	49.5	40.9	32.1	20.0	11.0	6.1
65	5.7	94.0	84.1	63.5	53.5	44.2	32.6	20.7	11.4	6.3
66	5.6	94.4	84.3	61.7	51.2	41.9	32.6	20.3	10.8	6.0
67	5.7	91.8	80.5	60.2	50.9	40.6	31.0	19.5	10.7	5.8

Table A-VI. Rochester Extraction Test Data

Obs	AC	3/4	1/2	1/4	1/8	#20	#40	#80	#200	Lot
		Percent Passing Sieve								
1	5.8	100.	97.4	78.6	41.5	32.0	25.1	9.7	4.9	1
2	5.9	100.	98.9	69.3	59.3	33.5	25.4	10.0	4.0	2
3	6.3	100.	97.3	69.3	60.0	33.8	25.4	9.8	2.7	3
4	6.3	100.	96.9	69.6	58.4	31.8	24.1	10.6	3.6	3
5	6.0	100.	97.0	69.6	51.2	31.4	25.2	9.9	3.7	3
6	5.9	100.	99.4	73.2	51.9	35.6	27.4	11.2	2.6	4
7	6.0	100.	98.2	69.3	52.0	34.0	25.1	7.9	2.3	4
8	6.0	100.	97.4	69.9	55.7	30.3	23.8	11.1	2.8	4
9	6.2	100.	97.2	62.6	60.5	35.7	27.1	9.8	3.6	5
0	6.4	100.	98.2	70.4	60.6	33.9	25.2	8.0	1.9	5
11	6.1	100.	96.6	71.1	59.9	34.9	25.3	9.6	2.0	5
12	5.7	100.	99.1	63.7	55.0	29.8	21.7	7.4	2.0	6
13	6.3	100.	98.2	68.5	58.3	32.7	24.0	9.7	1.8	6
14	6.5	100.	95.9	70.5	60.9	33.1	25.2	11.1	4.5	6
15	5.9	100.	98.1	70.8	59.7	34.0	24.9	9.2	2.2	7
16	6.1	100.	99.2	69.6	50.6	34.0	25.9	10.4	3.9	7
17	5.7	100.	97.8	70.3	60.3	32.2	23.5	9.2	3.8	7
18	6.7	100.	97.9	73.6	63.2	36.1	27.1	11.1	2.2	7
19	6.1	100.	98.2	71.0	59.8	31.8	26.4	7.9	4.2	8
20	6.5	100.	97.6	68.4	58.9	33.6	25.6	10.4	4.3	8
21	6.0	100.	100.	70.6	59.3	37.1	28.3	10.1	2.9	8
22	5.9	100.	98.3	70.1	59.1	34.4	27.7	12.6	4.4	8
23	5.8	100.	98.0	67.6	56.6	31.2	23.2	9.1	1.8	9
24	5.8	100.	98.9	74.8	60.7	36.0	26.4	10.2	2.7	9
25	6.0	100.	97.8	69.2	56.3	35.3	25.1	10.8	3.4	9
26	6.5	100.	96.0	65.5	54.2	30.2	22.8	8.4	2.8	9
27	6.4	100.	98.2	70.7	59.2	32.6	24.3	9.9	4.0	10
28	6.2	100.	99.6	75.9	62.9	33.3	23.9	9.2	3.3	10
29	6.2	100.	100.	87.9	61.6	36.7	27.8	12.3	4.5	10
30	5.9	100.	97.4	70.9	56.9	33.4	25.1	9.8	3.2	10
31	6.6	100.	97.8	70.2	60.6	33.7	25.1	8.6	4.1	11
32	6.2	100.	98.8	69.5	60.6	33.0	23.7	8.7	4.5	11
33	5.9	100.	99.2	70.1	57.9	33.2	25.9	11.1	4.6	11
34	5.9	100.	98.6	70.1	55.3	30.6	22.5	7.5	1.9	11
35	5.9	100.	99.1	76.3	61.3	33.8	25.7	11.1	4.8	12
36	5.9	100.	98.3	72.6	61.8	31.1	22.3	8.6	3.2	12
37	5.9	100.	95.8	71.8	61.4	33.6	25.7	10.4	3.6	12
38	6.2	100.	98.6	70.8	56.5	35.9	25.4	11.6	4.6	12
39	5.8	100.	98.8	78.2	58.4	36.4	27.1	10.3	3.1	13
40	5.8	100.	95.8	72.0	60.8	32.2	24.5	10.1	4.9	13

Table A-VI (Cont'd.)

Obs	AC	Percent Passing Sieve 3/4	1/2	1/4	1/8	#20	#40	#80	#200	Lot
41	5.3	100.	98.6	71.9	61.8	31.5	24.7	9.7	2.8	13
42	5.9	100.	98.4	65.6	55.2	29.2	21.6	8.6	3.2	13
43	5.8	100.	97.2	71.5	52.4	29.2	22.3	9.3	3.9	14
44	6.1	100.	98.7	76.8	61.5	33.1	24.5	10.3	2.5	14
45	6.5	100.	98.4	70.1	54.9	31.1	22.6	7.3	2.9	14
46	6.3	100.	97.9	71.1	55.7	32.9	25.1	10.9	3.2	14
47	5.9	100.	98.3	71.4	49.1	31.8	23.7	9.3	3.1	15
48	5.8	100.	97.6	73.1	59.7	32.3	24.5	10.6	4.1	15
49	6.3	100.	97.3	70.2	56.2	31.3	22.9	8.2	3.1	15
50	5.9	100.	97.7	69.5	55.3	30.9	22.1	7.7	2.3	15
51	5.8	100.	98.2	70.3	52.1	31.8	22.8	7.3	2.1	16
52	5.9	100.	98.6	70.1	55.3	31.6	24.0	9.5	4.3	16
53	5.8	100.	99.2	70.1	54.1	31.7	22.9	7.3	3.1	16